3. VITRIFICATION

Vitrification is a thermal treatment process used to convert various types of waste materials into chemically inert, stable, glass and crystalline waste forms. The process involves Joule heating the targeted waste materials to temperatures of 1,400–2,000°C, which is sufficient to melt the solid portion of the waste. Joule heating is the heat generated when electrical current flows through a medium that has electrical resistance. During vitrification, nonvolatile inorganic contaminants and radionuclides in the waste are chemically incorporated into the glass and crystalline matrix, while hazardous organic contaminants are either destroyed in place (via pyrolysis) or removed and captured in the accompanying off-gas system (depending on their volatility). Upon cooling, the vitrified waste form hardens into a durable glass and crystalline product with a leach resistance similar to that of basalt or obsidian. Semivolatile inorganic contaminants are also removed from the waste and captured in the off-gas system during the vitrification process. The vitrification process can be applied in a variety of in situ (in place), or ex situ (above ground) modes for buried waste.

3.1 Vitrification Process Overview

Joule heat is applied to batch vitrification processes via electrodes inserted in or around the waste materials to be processed. The processes use four cylindrical graphite electrodes connected to a large power transformer wired in a Scott-Tee arrangement (to convert 3-phase power to 2-phase power). Due to the batch nature of our proposed operation, vitrification will be initiated on waste materials that are not readily conductive, prior to becoming molten. To initiate melting of the waste, a conductive starter path of graphite and glass frit is placed between the electrodes, completing the circuit for the Scott-Tee transformer. Upon applying power to this circuit, the Joule heat created in the starter path will heat the starter path to temperatures sufficient to burn off the graphite material in the path. During this heating phase, both the glass frit in the starter path and the soil surrounding the starter path are heated to temperatures sufficient to become molten. Once this happens, a permanent conductive circuit path is created, allowing Joule heat to be supplied to the waste.

As more Joule heat is supplied to the waste, the amount of electrically conductive molten material begins to expand. This expanding melt decreases electrical resistance between the electrodes, due to the expanding diameter of the resistive circuit. The decreasing resistance results in increasing amperage being supplied to the melt (at constant voltage), thus, increasing Joule heating of the melt. This continues until the maximum amperage rating for a particular transformer tap is reached; afterwards, the voltage and resulting power begins to decrease. To maintain high rates of Joule heating in the melt, the power transformer must have multiple voltage taps that allow higher amperages (and, in turn, lower voltages) to be applied to the circuit as resistance decreases. Both the proposed in situ and ex situ vitrification processes will use a 3,750-kVA, Scott-Tee transformer, with 16 transformer taps. Using a 16-tap transformer allows more effective use of the existing power, and keeps the power factor (the ratio of average power to maximum power) for the transformer above 93% (versus approximately 77% for a 4-step transformer).

Once all of the waste material to be processed has become molten, power to the melt is terminated, and the molten monolith is allowed to cool. The vitrified waste form is a mixture of crystalline and vitreous phases that effectively incorporate radionuclides and heavy metals into the matrix. The waste

form has a compressive strength approximately ten times that of un-reinforced concrete and leach resistance similar to that of basalt, borosilicate glass, and alumino-silicate glass.

3.1.1   In Situ Vitrification Process Overview

The in situ vitrification (ISV) process being considered for V-tank waste treatment is called Planar-ISV. This process was developed by Geosafe Corporation in 1996, and is currently licensed in the United States to AMEC Earth and Environmental, Inc. The Planar-ISV technology offers significant advantages over conventional ISV technology (patented by Battelle Pacific Northwest Laboratories, in 1984) in treating waste forms in non-porous structures that contain significant volumes of volatile and semi-volatile materials (such as exist in the V-tanks). In particular, use of Planar-ISV eliminates the potential effects of pressure buildup and melt ejection that have occurred in previous conventional ISV melts.

ISV melt ejection has occurred during past conventional ISV processes. Figure 4 shows conventional ISV processing on a subsurface tank filled with potentially vaporizable material. Conventional ISV technology processes the contaminated soil/waste matrix from the top down. In processing tanks from the top down, there is the potential to trap volatile materials between the bottom of the advancing melt and the yet-to-be processed tank walls. As the volatile materials in the tank heat up, pressures can build in this region until the vapors formed are forced to pass through the molten mass. This can lead to a melt ejection event (MEE) and consequent overheating of the off-gas treatment hood and appurtenances.

In contrast, Planar-ISV technology minimizes the potential for MEEs by growing the melt from the sides into the area to be treated. Figure 5 illustrates Planar-ISV of the tank configuration illustrated in Figure 4. With Planar-ISV, the horizontal array of starter path material used in conventional ISV is replaced with two vertical planes of starter material. These vertical planes form two independent melts on the sides of the tank during the initial stages of the process. The presence of the side melts controls the initial melt process so that it can be focused for optimal treatment of the waste zone. Because the melts
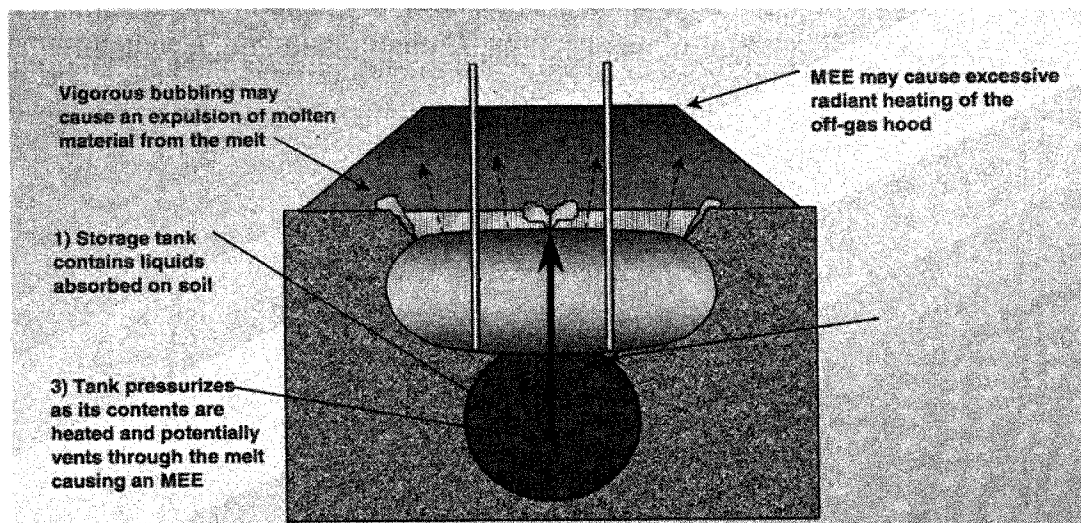

Figure 4. Conventional-ISV processing of a subsurface tank (figure courtesy of Geosafe).
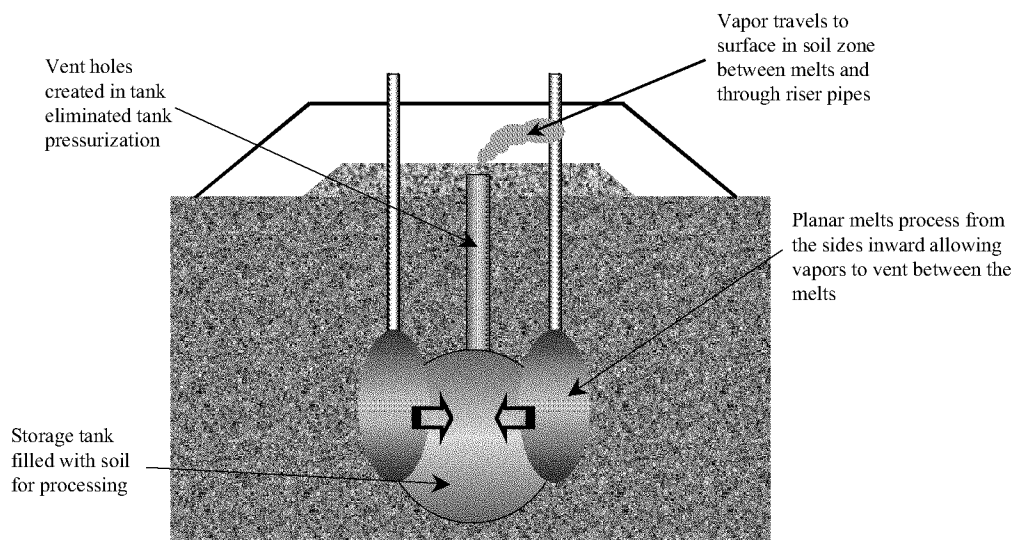
Figure 5. Illustration of Planar melting applied to an underground tank (figure courtesy of Geosafe).

are separated laterally during their initial stages, the underground tank can be processed in a predominantly sideways fashion. This maintains a permeable zone of soil in the tank, which allows a porous pathway for vapors and gases generated during ISV processing to move through the tank vents and manholes to the accompanying off-gas system. By the time the two melts have merged, the process will have effectively and safely removed all volatile materials (mainly water) in the treatment zone.

The application of Planar-ISV to underground tanks containing large quantities of liquid was successfully demonstrated in a treatability study performed by Geosafe in 1998 (INEEL 1998a), in support of the original WAG 1 ROD. The treatability study involved Planar-ISV processing of a 5,000-gal. stainless steel tank that was filled with INEEL soil and 33-vol% water. The treatability study results indicate that Planar-ISV can safely process a 5,000-gal. underground tank filled with water-saturated soil (a total of 1,670 gallons of water) with no melt expulsions. Based on pressure transducers located in the bottom of the 5,000-gal. tank, there were no increases in tank pressure experienced over the course of the demonstration test. Furthermore, thermocouple measurements within the tank and surrounding soils indicated that melting inside the 5,000-gal. tank was not appreciable until all of the water had evaporated from the tank. Figures 6 and 7 show the projected melt profiles for the 5,000-gal. tank after 96 hours and 106 hours of testing (when melting was terminated). As shown in these figures, the vents to the 5,000-gal. tank remained open to release vaporized material to the ISV off-gas system until after the Planar-ISV process was more than 90% complete and all of the water had evaporated from the tank. The treatability study included conducting tests demonstrating the ability to initiate vitrification in the soil with an electrode spacing of 22 feet (required for the V-tanks), with no implementation concerns.

Implementing Planar-ISV on the V-tanks requires the entire tank to be filled. Current plans are to use INEEL soil as fill material for the proposed Planar-ISV process. The purpose of filling the tank is to prevent melt upsets that could result from a sudden collapse of the tank (and the resulting air exchange associated with such a collapse). The starter planes for the Planar-ISV operation are generally inserted at their desired initial position (a depth equivalent to 0-2 feet below the top half of the underground tank) by
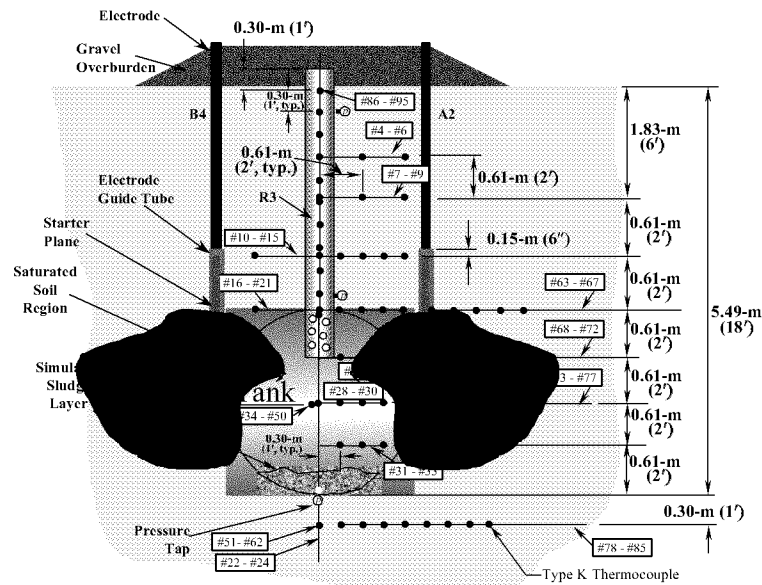
Figure 6. Simulated V-tank treatability test using Planar-ISV—estimated melt shape at 96 hours.
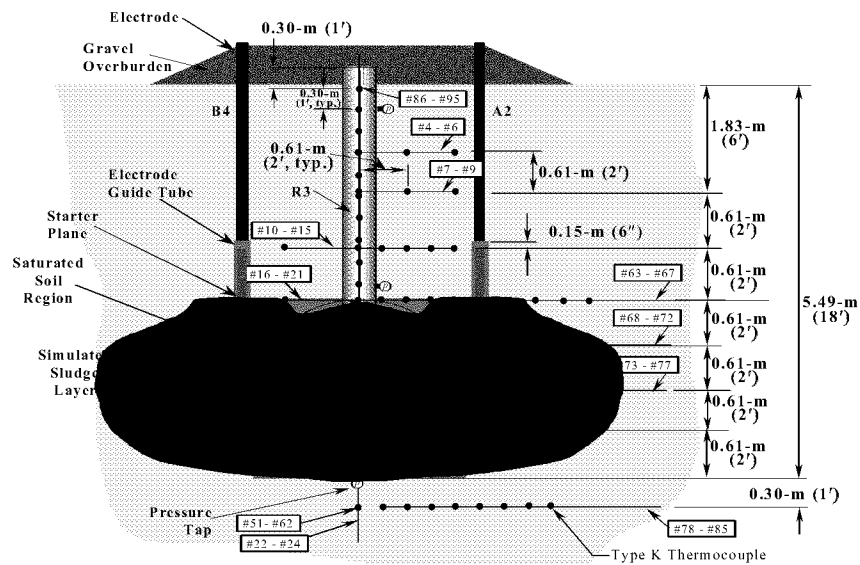
Figure 7. Simulated V-tank treatability test using Planar-ISV—estimated melt shape at 106 hours.

trenching and back filling the soil surrounding the tank. Starter path placement may also be performed using in situ injection, if desired.

The Planar-ISV technology uses the same 3-phase to 2-phase Scott-Tee electrical design that is used for conventional ISV processing. However, the two resultant phases are initially placed parallel to each other, within the same electrode plane, rather than crossing each other (as preferred for conventional ISV). Cross-phase circuitry can be used to accelerate Planar-ISV processing of the tank, once the two melts come in contact with each other.

The Planar-ISV process can be performed on any one of the V-tanks (assuming that the V-tank contents are consolidated into one tank), or all four V-tanks, in three melts (if avoiding sludge consolidation is desirable). All four tanks can be processed in three melts due to the proximity and arrangement of the tanks. For our planning purposes, it was decided to consolidate the V-tank contents into Tank V-2, and perform a single Planar-ISV melt. The increase in cost to purchase and operate the necessary sludge transfer system will be more than offset by the decreased cost of performing only one vitrification melt.

3.1.2   Ex Situ Vitrification Process Overview

The proposed approach for the ex situ vitrification (ESV) process also involves a 2-phase, top-down vitrification process. However, there is no concern associated with melt expulsion events during ESV because the ESV process will not be performed in a closed container that could allow accumulation of vaporizing materials. Rather, the ESV process will be performed in 20-yd^3 roll-off boxes that have been insulated with semi-porous insulation materials that allow vapors to pass to the vitrification hood and off-gas system, without a pressure build-up. However, ESV will require significant radiation shielding for the waste transfer system, vitrification unit(s), containment hood, and the off-gas subsystem up through the first HEPA filter. Remote or semi-remote operating methods will also be required in these areas. Storage, handling, and transportation of the vitrified waste containers may also require shielding and semi-remote operating methods.

The proposed batch ESV technology involves a total of three ESV melts on V-tank wastes that have been placed in six 20-yd^3 roll-off boxes. Two roll-off boxes will be simultaneously vitrified during each of the three ESV melts, using two of the four electrode connections on each box. To keep the vitrification process from melting the sides of the roll-off boxes, the internal sides and bottom of the roll-off boxes are surrounded with 6 m^3 of pressed thermal insulation boards and silica sand. This leaves 6 m^3 of available space within each 20-yd^3 roll-off box for soil and waste addition. Slip forms will be used to keep the silica sand in place between the thermal insulation board and the container wall during roll-off box preparation. Once the internal sides of each roll-off box have been insulated, plastic will be used to line the bottom and sides of the refractory liner interior (against the slip form). Type K thermocouples will be placed at the interior edges of the refractory liner material to verify vitrification process completion for each roll-off box.

The roll-off boxes will then be filled with a predetermined amount of INEEL soil to improve implementation of the vitrification process and ensure that the sludge can be vitrified in a manner that produces a high quality waste form. The resultant vitrified waste form will have a transuranic (TRU) content under 10 nCi/g, thereby ensuring its eventual disposal at the ICDF. During soil placement, the vitrification starter paths and electrodes will also be placed in each roll-off box. The conductive electrodes

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will consist of two 12-in. diameter pressed graphite rods placed vertically in each roll-off box, near the short ends of the box, while the vitrification starter path consists of a conductive layer of starter path (graphite and glass frit) placed between the two vertical electrodes within each roll-off box. After starter path and electrode placement, the sludge from the various V-tanks will be transferred to the top of the soil area within each roll-off box. The composition of the sludge sediment, relative to INEEL soil, is similar enough that there is no need to mix the tank sludge with the pre-determined soil volume before placing it in the roll-off boxes. Rather, the sludge can be simply poured over the top of the soil, while being careful to avoid dislodging the electrically conductive starter path. Free liquids from the tank sludges will flow into the soil and become absorbed within it.

The three batch ESV vitrification operations will be performed sequentially. Based on mass balance calculations contained in Appendix E, portions of the various V-tank sludges may have to be mixed with other tank sludges as part of each batch ESV process. Current estimates are that the sludge from Tank V-1 will fill approximately 1.5 roll-off boxes; the sludge from Tank V-2 will fill 0.75 roll-off boxes, the sludge from Tank V-3 will fill 1.75 roll-off boxes, and the sludge from Tank V-9 will fill 2 roll-off boxes. Plans include conducting each melting operation (2 roll-off boxes per melt) over a 48-hour time period, with an additional 24 hours between melts to allow the vitrified waste forms to cool. The two roll-off boxes for each succeeding melt will be prepared during the 24-hour cooling period for the previous melt.

Similar ESV batch processes have been conducted by AMEC Earth and Environmental using a process called In-Container Vitrification (ICV). The ICV process has been selected in Australia as an alternative to incineration in the treatment of concentrated chlorinated organic waste, which includes PCBs and dioxins. In addition, a 30-ton ICV process has been permitted in Japan for the treatment of soils contaminated with high concentrations of dioxins. The ICV process is expected to maintain the same regulatory approvals that currently exist for conventional ISV treatment of PCB wastes (eliminating the need to apply for a Toxic Substances Control Act (TSCA) license before using it on the V-tanks).

3.1.3 Vitrification Process Off-Gas Treatment

Both Planar-ISV and ESV will collect the off-gases using a single stainless steel hood placed over the material being vitrified (Tank V-2 and portions of Tanks V-1 and V-3 for the Planar-ISV process, or both roll-off boxes for the batch ESV process). The hood will direct the vitrification off-gases through an off-gas collection system operated with an oversized blower (1800 scfm) and variable in-leakage rates sufficient to maintain a hood vacuum over the entire range of off-gas release rates expected during the batch vitrification process. This allows for varying rates of off-gas release from the batch vitrification processes, without process upsets.

Plans are to treat Planar-ISV and batch ESV off-gases in a similar manner. A simplified process flow diagram is shown in Figure 8. The collected off-gases, after mixing with air (from varying in-leakage rates, within the off-gas hood), initially flow through a super heater and High Efficiency Particulate Air (HEPA) filter system before entering the off-gas system. This step minimizes radionuclide contamination within the off-gas system. Following HEPA filtration, the off-gas is passed through a quencher, a 2-stage venturi scrubber, a condenser, and a mist eliminator. This ensemble of unit operations cools the off-gases to 40–70°C (depending on the specific vitrification operation), while removing 98% of the acid gases from the off-gas stream. The cooled off-gases are reheated 8–12°C (to avoid further condensation) before a second-stage of HEPA filtration (for backup purposes). The off-gas is then passed through a granular activated carbon (GAC) bed that captures any residual organic vapors not destroyed by
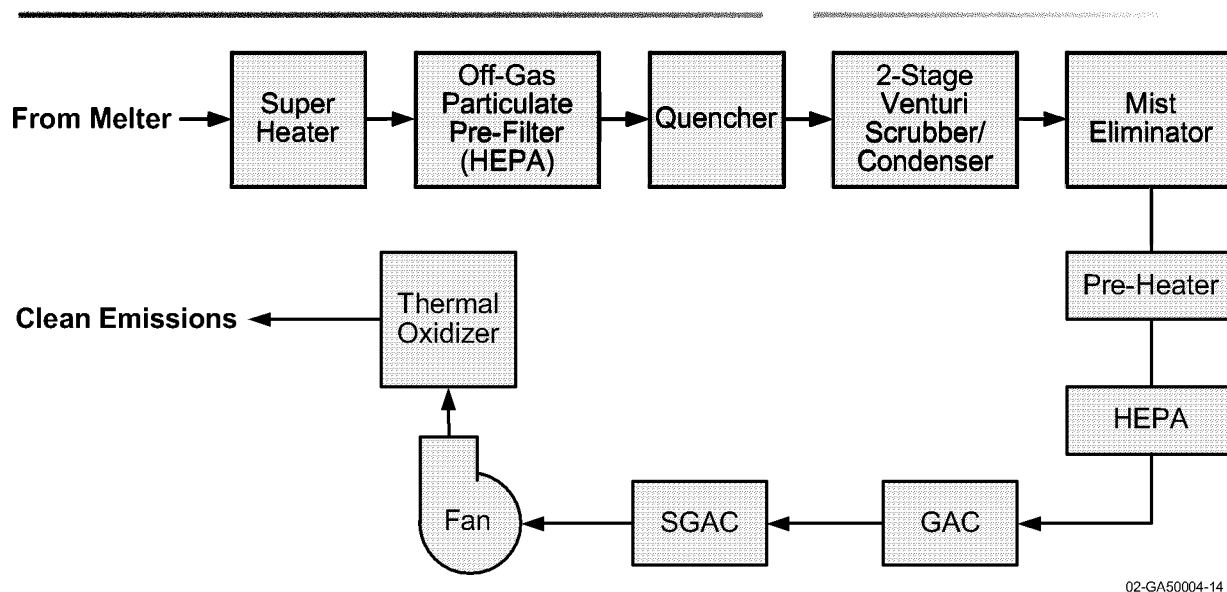
Figure 8. Simplified off-gas process flow diagram for both vitrification systems.

the vitrification process. This is followed by a sulfur-impregnated GAC (SGAC) bed that captures the mercury off-gas vapors. The relatively clean off-gas is then polished via a thermal oxidizer system, prior to release to the environment. The thermal oxidizer should also destroy any residual carbon monoxide that may have been produced. The off-gas released during each vitrification process is expected to meet MACT standards for incinerators, even though the overall process is not considered as an incinerator.

3.2   Key Assumptions

Key assumptions specific to regulatory compliance, process efficiencies, analytical data, etc., are listed below:

- Sufficient power is currently available at TAN for vitrification and off-gas treatment and control. This was confirmed in discussions with electrical supply operators at TAN, who stated that the grid is able to support up to 9.2 MW of power, and the current maximum power load to TAN is 3.5 MW in winter. In addition, there is a 9.2 MW backup power grid that could be used in short-term emergencies. Therefore, TAN is currently able to supply the necessary power (up to 4 MW) needed for vitrification. This is also expected to be the case in FY-05, when V-tank remediation is expected to commence.

- Additional utilities, such as a water supply, are available from TAN to support V-tank remediation.

- For ISV operations only, TAN-616 will have undergone decontamination and decommissioning (D&D), and will be removed from the V-tank Area of Concern (AOC) before initiating vitrification. TAN-616 D&D is currently planned for FY-03 and FY-04, so this assumption is based on maintaining the currently planned schedule. Without total removal of TAN-616, Planar-ISV processing of the V-tanks would require an expensive refractory barrier designed to protect

TAN-616. In addition, the ISV off-gas hood design would be complicated by the proximity of TAN-616.

- For ISV operations only, all V-tank connections to adjacent buildings at TAN will be cut and capped before initiating vitrification. In addition, any piping or appurtenances not related to the V-tanks that pass through the projected area of the Planar-ISV melt (approximately 15 feet from the outer dimensions of Tank V-2) will be re-routed or disconnected before initiating vitrification. Both of these operations are expected to be part of the Early Remedial Actions. Excavation and removal of this piping will remain the responsibility of the V-tank remediation project, however.

- Decanting additional liquid from the V-tanks can be performed using the same decant system used to decant the initial 6,000 gallons of liquid from Tank V-3 before initiating this operation. Decanting additional supernatant will reduce the vitrification time and off-gas condensate volume that must be handled during vitrification, to the extent feasible. The waste transfer system may require significant radiation shielding.

- For ISV only, expanding the man-holes on Tanks V-1, V-2, and V-3 to a 6-ft diameter before soil filling is sufficient to allow soil filling of all three tanks, while providing sufficient venting for Tank V-2 during vitrification operations.

- The proposed vitrification processes, in combination with SGAC filtration of the mercury-contaminated off-gas, will be judged equivalent to regulatory requirements for retorting and amalgamating mercury from hazardous wastes containing greater than 260 ppm mercury (as is present in Tank V-9). This is only a concern if the contents of Tank V-9 are to be treated as a separate waste stream.

- The off-gas behavior for both vitrification operations is such that all volatile organic contaminants and water are released to the off-gas system in a relatively untreated state, before the residual material rises to a temperature over 150°C. This means that there should be no hydrogen chloride formation associated with the release of VOCs to the off-gas system. This assumption is based on documented evidence that hydrogen chloride formation does not occur below temperatures of 150°C, long after the VOCs have volatilized and been transported to the vitrification off-gas system.

- In both vitrification processes, the melt completely pyrolyzes all semivolatile organics (volatilization temperatures over 150°C) before their release to the off-gas system. In addition, we assume that all chlorinated fragments resulting from this pyrolysis will be converted to HCl, along with all other inorganic chloride compounds. This assumption is based on past experience that indicates significant pyrolysis of semivolatile organics by the vitrification process.

- The off-gas system, as designed, will be sufficient to meet MACT standards for off-gas emissions, if that becomes a regulatory requirement.

- On-Site trial burns will not be required for implementation and/or waste treatment. However, mock-up demonstrations of the proposed processes will be required as part of obtaining operational approval to proceed.

- The GAC and SGAC beds will be characterized after completion of the treatment of the V-tank waste. If characterization of the beds reveals the need for treatment or noncompliance with the ICDF WAC, the beds will be shipped off-Site for treatment and disposal. If the beds do not require

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treatment and meet the ICDF WAC then the waste will be shipped to ICDF for disposal. (See last bullet of Section 2.1.)

- The off-gas system GAC filter will be sized to preclude organic contaminant breakthrough for either vitrification process. This will ensure minimal organic contaminants becoming absorbed on the SGAC filter, allowing the SGAC filters to be disposed of at the ICDF. All secondary waste is expected to meet the ICDF WAC and be disposed of in the ICDF with the possible exception of the GAC and SGAC beds.

- Contamination control during fracturing of the vitrified waste form (ISV only), and excavation of contaminated soil can be managed by maintaining slightly damp soil conditions, placing wind restriction on operation, temporary tarping, etc., as opposed to large temporary containment structures.

3.3   Technical and Functional Requirements

3.3.1   ISV Technical and Functional Requirements

Liquid Decanting Subsystem

The liquid decanting subsystem shall have the following capabilities:

- Liquid removal capability to within 4 in. of the top of the V-tank sludge phase, without significant sludge phase disturbance

- Capability to be monitored (pressure, flow, etc.) real-time

- Remote video visual monitoring capability at the decant suction inlet for sludge disturbance

- Capability to stop or divert liquid decanting if visual observation indicates sludge entrainment before contaminating liquid already collected

- Capability to return liquid with entrained sludge to the V-tank in a manner that minimizes disturbance of the sediment layer

- Capability of in-line organic contaminant removal from the decanted liquid, thereby allowing solidification of the decanted liquid in a manner that meets LDRs.

Planar-ISV Subsystem

The Planar-ISV subsystem shall have the following capabilities:

- Capability to vitrify a 10,000-gal. V-tank containing the sludge and liquid from all four V-tanks and sufficient soil added to fill the tank. The tank is estimated to contain approximately 40 vol% liquid.

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Operating Control Subsystem

The operating control subsystem shall have the following capabilities:

- Capability to use a backup electric power source for the off-gas system, with batch logic sequencing to allow automatic off-gas system backup power startup in the event of a power outage
- Capability to automatically control all off-gas equipment associated with the process
- Capability to control unit operations so that operating control limits are met and maintained
- Capability to use batch logic sequencing, to be automatically implemented in the event of process upsets (including connecting and starting a back-up blower, if the primary blower fails)
- Capability to control the applied current to the multistep transformers
- Capability for remote visual observation of the ground surface underneath the ISV off-gas hood.

Containment Hood Subsystem

The containment hood subsystem shall have the following capabilities:

- Capability to encompass an area 60-ft. by 45-ft., based on the expected 40-ft. by 25-ft. melt area plus 20 ft. in each dimension to ensure coverage of the maximum extent of the 100°C isotherm (8 ft. away from the melt)
- Capability to control in-leakage to maintain hood vacuum and prevent releases from the hood to the surroundings.

Off-Gas Subsystem

The off-gas subsystem shall have the following capabilities:

- Capability for component (GAC filters, HEPA filters, etc.) removal and change-out during daily operation (if necessary)
- Equipment sized to minimize the potential for off gas system component (GAC filters, SGAC filters, etc.) change-out during the ISV process
- Backup capability for critical back-up systems (redundant HEPA filters, backup blowers, etc.)
- Capable of process monitoring (temperature, pressure drop, etc.) between filtration units (i.e., HEPA filters, GAC filters)
- Capability to remove hazardous volatile and semivolatile organic and inorganic materials from the off-gas sufficiently to meet air permitting requirements
- Capability to prevent water vapor condensation in the off-gas subsystem except in the quench/scrub/condenser/ME units
- Capability to capture nonvolatile particulates entrained in the off-gas exiting the hood during processing and returning them to the vitrifying melt

- Capability to withstand temperatures up to 500°C in front of the quench/scrubber/condenser unit

- Capable of controlling pH in scrubber solutions, via simple caustic addition

- Capability to transfer (by gravity feed, pump, etc.) scrubber and collected condensate solutions to 55-gal. drums for solidification/stabilization and disposal.

3.3.2 ESV Technical and Functional Requirements

Liquid Decanting Subsystem

The liquid decanting subsystem shall have the following capabilities:

- Liquid removal capability to within 4 in. of the top of the V-tank sludge phase, without significant sludge phase disturbance

- Capability to be monitored (pressure, flow, etc.) real-time

- Remote video visual monitoring capability at the decant suction inlet for sludge disturbance

- Capability to stop or divert liquid decanting if visual observation indicates sludge entrainment before contaminating liquid already collected

- Capability to return liquid with entrained sludge to the V-tank.

Batch ESV Subsystem

- Capable of completely vitrifying the waste contents of two 20-yd^3 roll-off boxes simultaneously, using single-phase power (two electrodes) within each of the roll-off boxes

- Capable of processing two roll-off boxes simultaneously over a 48-hour period

- Capable of simultaneously processing the roll-off boxes without significant transients or melt pressurizations sufficient to lose containment to the off-gas collection hood during ESV processing

- Capable of processing the layered sludge and soil within each roll-off box without having to mix the soil and sludge together.

Operating Control Subsystem

- Capable of operation using a secondary (backup) power source (electric generator, etc.), with batch logic sequencing to allow for automatic backup power startup in the event of a power outage

- Capable of automatic control of all off-gas equipment associated with the process

- Capable of controlling unit operations so that operating control limits are met and maintained

- Capable of batch logic sequencing, which will be automatically implemented in the event of process upsets (including connection and startup of a back-up blower if the primary blower fails)

- Capable of controlling the applied current to the multistep transformers

- Capable of remote visual observation of the ground surface underneath the ESV off-gas hood.

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Containment Hood

- Large enough to encompass two 20-yd^3 roll-off boxes within the hood. This will require the rectangular hood to have a span of at least 16-ft in the short direction and 24-ft in the long direction. In addition, the hood must be high enough to allow two 6-ft tall roll-off boxes to fit inside it.

- Designed to facilitate crane manipulation to lift the hood from over the roll-off boxes and replace the hood directly over roll-off boxes, including ease of disconnecting and reconnecting attached off-gas pipes.

- Capable of allowing and controlling in-leakage to the off-gas system to maintain process vacuum and eliminate off-gas releases outside of the hood.

Off-Gas Subsystem

- Capable of component (GAC filters, HEPA filters, etc.) removal and replacement during daily operation

- Sufficiently sized to minimize the potential for off-gas systems (GAC filters, SGAC filters, etc.) change-out during the ESV process

- Capable of providing critical back-up systems (redundant HEPA filters, backup blowers, etc.)

- Capable of process monitoring (organics, inorganics, participate, etc.) between filtration units (i.e., HEPA filters, GAC filters)

- Capable of filtering and removing hazardous volatile and semivolatile organic and inorganic materials from the off-gas before their release to the environment (using equipment such as condenser, scrubber, activated carbon filters, thermal oxidizer, etc.)

- Capable of avoiding water-vapor condensation in the system except where desired (the condenser unit)

- Capable of capturing nonvolatile fines that have been entrained to the off-gas during processing and returning them to the vitrifying melt

- Capable of withstanding temperatures up to 500°C in front of the quench/scrubber/condenser unit

- Capable of providing secondary cooling to the scrubber solutions and collected condensate

- Capable of handling and storing condenser and scrubber waste solutions

- Capable of transferring (gravity feed, pumping, etc.) waste solutions to containers or holding tanks.

3.4   In Situ Vitrification

3.4.1   ISV Overview

Figure 9 is the process flow diagram (PFD) for the proposed ISV operation. The PFD is numbered and lettered to identify the major ISV components and their associated subcomponents. The PFD numbers correspond with the stream numbers shown on the summary mass balance (Table 4) and the detailed mass

22

Off-Gas to
Atmosphere

Fines Return

Soil
(Sufficient
to fill tank)

Off-Gas
(2 Stages)
≤100°C
≥100°C

Metal
HEPA
Filter

Fuel
Requirement

Thermal
Oxidizer

**4 - Sludge & Liquid,
Post-Decant**

**1 -V-Tank
Contents**

> 150°C

Blower

Filtered
Off-Gas

**10 - SGAC
Filters**

Air
In-Leakage

**5 – Waste and
Soil Composite**

Quench

Decant
Liquid
(4 in. above
sediments)

Wet Spray
Scrubber, w/
Condenser

**9 - GAC
Filters**

Surrounding
Soil

**6 - Glassified
Waste Form,
Post-Vitrification**

Mist
Eliminator

~70°C

**8 - HEPA
Filters**

~82°C

Sample

Caustic
Addition

Collected
Condensate

Heater

**2 -GAC
Decant Filter**

Fracture & Excavate
Vitrified Monolith

Filtered
Decant

Vitrified Waste
Form Disposal

**3 - Grouted
Decant
Solution**

**7 - Grouted
Condensate
Solution**

Aqua-Set

Aqua-Set
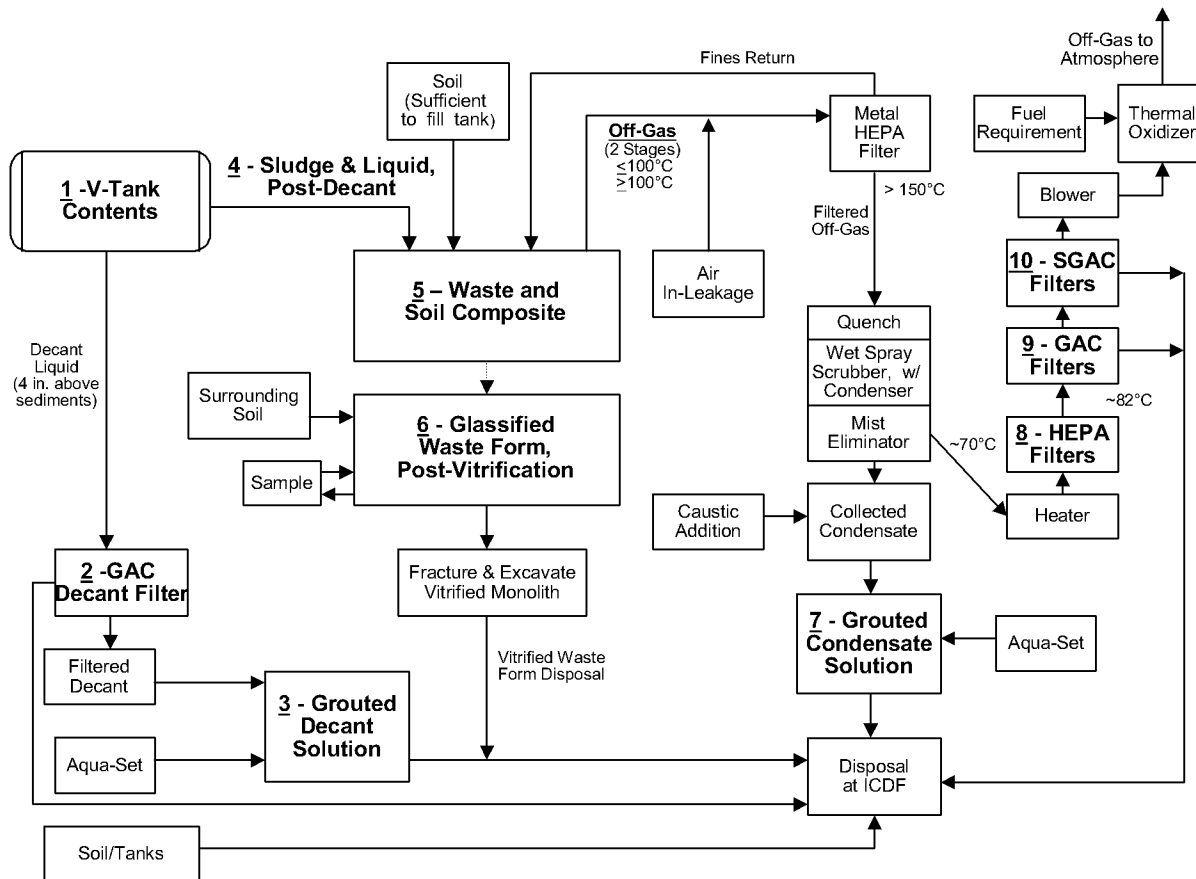
Disposal
at ICDF

Soil/Tanks

Figure 9. In situ vitrification with on-Site disposal/off-gas treatment process flow diagram.

Table 4. Summary mass balance for the ISV process.

Stream Number	V-tank Contents	GAC Decant Filter	Grouted Decant Solution	Sludge & Liquid, Post-Decant	Decanted Sludge & Added Soil, Pre-Vitrification	Glassified Waste Form, Post-Vitrification	Grouted Condensate Solution	HEPA Filters	GAC Filter	SGAC Filter
Stream Name	1	2	3	4	5	6	7	8	9	10
Component										
Inorganics										
Cd (mg/kg)	2.02E+01	0	3.09E-02	4.32E+01	7.22E+00	0	7.28E-04	1.14E+00	0	0
Chlorides (mg/kg)	1.36E+02	0	9.42E-01	1.42E+02	2.37E+01	0	4.80E+01	0	0	0
Cr (mg/kg)	5.96E+02	0	9.82E-02	1.28E+03	2.72E+02	1.05E+02	0	0	0	0
Hg (mg/kg)	2.59E+02	trace	7.99E-02	5.55E+02	9.27E+01	0	trace	trace	trace	7.37E+03
Pb (mg/kg)	2.82E+02	0	1.82E-01	6.03E+02	1.01E+02	1.41E+01	trace	trace	0	0
VOCs										
PCE (mg/kg)	2.37E+02	4.27E+02	0	5.07E+02	8.47E+01	0	0	0	6.74E+03	trace
TCA (mg/kg)	1.05E+02	1.22E+03	0	2.23E+02	3.72E+01	0	0	0	2.96E+03	trace
TCE (mg/kg)	8.54E+02	8.97E+03	0	1.82E+03	3.05E+02	0	0	0	2.42E+04	trace
SVOCs										
BEHP (mg/kg)	9.10E+02	1.53E+02	0	1.95E+03	3.26E+02	0	0	0	trace	trace
Araclor-1260 (mg/kg)	3.59E+01	1.45E+02	0	7.68E+01	1.28E+01	0	0	0	trace	trace
Radionuclides										
Cs-137 (nCi/g)	1.98E+03		4.13E+00	4.23E+03	7.06E+02	9.91E+01	3.42E-05	trace	0	0
Sr-90 (nCi/g)	3.68E+03		7.74E+00	7.87E+03	1.32E+03	1.85E+02	2.13E-05	trace	0	0
TRU (nCi/g)	8.57E+00		3.03E-03	1.84E+01	3.07E+00	4.30E-01	4.96E-08	trace	0	0
Other										
Total Carbon (mg/kg)	2.53E+04	8.90E+04	0	5.42E+04	2.24E+04	0	0	0	trace	trace

*Chlorides shown in the Grouted Condensate Solution include those derived from PCB destruction.

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balance for the ISV (Appendix A). A summary mass balance for ISV, showing key constituents and CFTs at major points in the process, is shown in Section 3.4.2, in Table 4.

As previously described in Section 3.1, the ISV technology under consideration is Planar-ISV.

Decanting additional liquid from each tank removes as much liquid from the tanks as feasible before vitrification to maximize the efficiency of the thermal vitrification process, i.e. decreased vitrification duration and power requirements. [Note: Decanting is done as an initial step for both vitrification alternatives, but for the alternatives comparison in this report, is unique only to the vitrification flowsheets.] Based on the mass balances of the V-tank contents, it appears that the sludge phase alone on each of the tanks contains 58-72% liquid. There is sufficient liquid to slurry and remove all of the tank contents. Furthermore, the liquid phase contaminants can be disposed of with simple stabilization (following carbon adsorption), whereas the solids require additional treatment due to the presence of strongly partitioned organics, heavy metals, and remote-handled radiation field.

Following decanting, the liquid and sludge phases from Tanks V-1, V-2, V-3, and V-9 will be mixed into the contents of Tank V-2. This consolidates the wastes into one tank so that only one Planar-ISV melt will have to be performed. The intent is to minimize the heel left behind in each emptied tank by aggressively slurrying using a jet mixing system manufactured by American Electronics Association (AEA) Technologies (or equivalent). This kind of system is expected to remove nearly all of the tank heals. Significant radiation shielding will be required for the waste transfer system and semi-remote operating methods will be needed for the transfers.

Use of Tank V-2 for waste consolidation will minimize the footprint for excavation of the residual tanks and contaminated soil from the V-tank AOC following Planar-ISV processing. Tank V-9 is too small for the consolidated waste, and vitrification of Tanks V-1 or V-3 would increase the volume of material to be excavated, since ISV melts typically grow to a diameter 15 ft greater than the original tank diameter (7.5-ft. all the way around the 10-ft diameter tank). Use of Tank V-2 results in partial melting of the V-1 and V-3 tank shells, reducing the sizing effort for the remainder of the tanks following post-ISV excavation. Much of the soil in the area of contamination will also be vitrified, which simplifies contamination control.

Following waste consolidation, the remaining volume in Tank V-2 will be filled with soil (from the V-tank AOC or possibly stabilized material from the PM-2A tanks, also located at TAN). Filling the tank with additional soil (or PM-2A material) is necessary to absorb free liquids within the consolidated V-tank material and eliminate potential off-gas transients that may result from the presence of free liquids. Investigation-derived wastes or the entire ARA-16 tank can also be added to Tank V-2 before vitrification.

Soil will also be needed to fill both Tanks V-1 and V-3, because the ISV melt is expected to encompass approximately 45% of both tanks. If the adjacent tanks were left empty, the melt could run into either of the adjacent empty tanks, resulting in the loss of a conductive, Joule-heated path between the electrodes and the vitrified material. Filling the entire tank also prevents any inadvertent tank collapses that could cause an air exchange event, resulting in contamination releases underneath the ISV off-gas hood (complicating equipment demobilization activities).

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The manhole for each tank will be expanded from 20 in. in diameter to the 6-ft. diameter of the manhole access pit to facilitate filling the tanks with soil. Expanding the tank manholes is also expected to eliminate the need for additional venting for Tank-V-2 before initiating Planar-ISV processing. Avoiding venting through the overburden reduces concern over semivolatile contaminant deposition in the overburden during Planar-ISV, since any vaporized semivolatiles will be vented above ground level instead of into the soil overburden.

After filling the tanks, a 3-ft wide, 17-ft deep, 22-ft long trench will be dug on both sides of Tank V-2 for electrode and starter path placement. The presence of steel tank shells on both sides of the trenches eliminates the need for extensive trench shoring. Two 12-in. diameter graphite electrodes in PVC casings will be placed vertically on opposite sides of each trench, approximately 20-ft apart, with the bottoms of the PVC casing placed to a depth of 17-ft, and the bottom of the electrodes at a depth of approximately 15-ft (with soil placed in the PVC between the 15-ft and 17-ft depth to support the electrodes). Graphite material will then be placed to a height of approximately 5-ft in the space between the PVC casing and the graphite electrode. A precompressed starter path (consisting of graphite and glass frit), 20-ft long, less than 5-ft wide, and less than 1-in thick, will then be placed between the PVC casings at a depth of 10-15 ft (with soil added under the starter path, as necessary). After preliminary back filling (to a depth of approximately 10-ft), the PVC casings for each graphite electrode will be removed, and continuity between the electrodes in each trench will be verified. The trenches will then be completely back-filled.

After placing the starter paths, the off-gas hood will be placed over the vitrification area, the electrodes will be connected to the power transformers (via the electrode guide tubes), the pipe from the off-gas hood to the off-gas trailer will be attached, and vitrification will commence. Based on previous Planar-ISV processes, the entire V-tank contents should be melted at an efficiency of approximately 0.7 kWh/kg of material, with approximately 52% subsidence in melt volume. The ISV melt is expected to process approximately 45% of Tanks V-1 and V-3, in addition to all of Tank V-2.

Based on previous Planar-ISV melts, the resulting off-gas is expected to be relatively cool (<150°C) at ground surface. The off-gas should be relatively high in carbon monoxide, hydrogen chloride, mercury, and volatile organic contaminants, and relatively low in entrained radionuclides and cesium. This is due to the subsurface nature of Planar-ISV (which allows for cooling before the off-gas gets to the hood), and the presence of a substantial air in-leakage rate during Planar-ISV. The air in-leakage prevents contamination release where the containment (off-gas hood) is not sealed during the varying stages of Planar-ISV processing. During Planar-ISV, the off-gas release rate is expected to vary from 24 m^3/min during the initial part of the process (when volatilized liquid and VOCs are released) to only 3 m^3/min during the later phases of the process (when hydrogen chloride, mercury, and carbon monoxide are released). To maintain constant off-gas flow, the ISV off-gas system has been designed with a 50 m^3/min (1800 cfm) blower and varying air in-leakage to prevent loss of hood vacuum during the ISV process.

The off-gas system has two stages of HEPA filtration (with the first stage at the beginning of the off-gas train to minimize contamination of the rest of the system, and the second stage near the end for back-up purposes) to capture residual radionuclides and cesium. To capture hydrogen chloride, the off-gas system is equipped with a quench tower, a two-stage Venturi scrubber/condenser, and a high efficiency mist eliminator. The off-gas system is equipped with GAC and SGAC filters to capture the

VOCs and mercury following scrubbing. For carbon monoxide removal, a propane-fueled thermal oxidizer is the final unit in the off-gas system, downstream of the blower.

After ISV, the waste form will be allowed to cool for 6-12 months. The decanted liquid and process condensate collected will be placed in 55-gal. drums and solidified with Aquaset, then disposed of at the ICDF. The GAC and SGAC filters will be macroencapsulated on-Site, within their respective housings, with the macroencapsulated GAC filters sent off-Site for disposal (due to the high organic concentrations that are present), and the SGAC filters disposed of at ICDF. (See last bullet of Section 2.1.) Used HEPA filters will be macroencapsulated and disposed of at the ICDF. Any contaminated equipment, material, and personal protective equipment (PPE) that cannot be decontaminated for clean release will also be disposed of as debris at the ICDF.

Following 6 to 12 months of cooling, the V-tank area will be excavated to remove the vitrified waste form, remaining tank materials, and contaminated soil from the AOC. As part of the excavation process, the solidified waste form will be fractured using a proven crane- or backhoe-mounted vibratory hammer. The entire contents of the excavated AOC will be disposed of at the ICDF without packaging (the excavated material will be transported in and dumped out of roll-off boxes).

3.4.2   Mass Balance Summary

A summary mass balance for ISV is shown in Table 4. A more detailed mass balance is in Appendix C. Table 4 shows the amount of the CFTs, liquid, solids, and added materials, along with other information, at major points in the process.

3.4.3   Major Process Steps

The steps in the ISV process have been segregated into twelve major groupings. These major groupings correspond to the total number of major process operations identified for the proposed ISV processing technology. These include:

- Decant excess liquid from all four V-tanks, prior to performing in situ vitrification.

- Slurry and transfer the sludge and liquid phases from Tanks V-1, V-3, and V-9 into Tank V-2 using the AEA Jet Mixing System (or equivalent), expanding the man-ways in Tanks V-1, V-2, and V-3, then adding sufficient soil to fill Tanks V-1, V-2, and V-3. (As an alternative, it may be desirable to excavate Tank V-9 without removing its contents, and place the entire filled Tank V-9 in Tank V-2, prior to adding soil, if it is found that there is limited ability to pump the contents of Tank V-9 into Tank V-2, using the AEA system or equivalent.)

- Vitrification preparation, including trenching and placing the electrode starter planes on both sides of Tank V-2, backfilling the trenches, connecting the electrodes to the supplied power, and placing the off-gas hood over Tank V-2 (and parts of Tanks V-1 and V-3).

- Vitrification operations, including melt monitoring, off-gas collection, and first HEPA filtering stage.

- Off-gas quenching, 2-stage scrubbing, condensing, and eliminating mist from the off-gas stream to remove acid gases from the off-gas.

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- Off-gas HEPA filtration and thermal oxidation, including GAC and SGAC filtration of the cooled off-gas stream to remove residual organics and mercury contaminants from the off-gas system.

- Polishing the treated off-gas using a propane-fueled thermal oxidizer to guarantee complete destruction of the organic vapors (those not captured by the GAC filter) and convert carbon monoxide to carbon dioxide before release to the environment. Post-stack sampling is included in this process operation.

- GAC filtration of the decanted liquid (to remove residual organics from the liquid), followed by 55-gal. drum containerization and stabilization of the decant and condensate liquids, and stabilization of the liquids using Aquaset, or an equivalent liquid absorbent.

- Scrub/condensate solution collection, caustic system use to adjust the solution, containerize in 55-gal drums, including sampling to confirm LDRs met.

- Cement the internal contents of the HEPA, GAC, and SGAC filter housings to stabilize them as debris waste, followed by macroencapsulation of the filters as debris. (See last bullet of Section 2.1.)

- Fracture solidified ISV glass and crystalline monolith, after sufficient cooling, using a crane- or backhoe-mounted vibratory hammer, size remaining tank shells, package waste. This step includes removing and packaging the phosphorus layer created on top of the vitrified waste form by the ISV process.

- Excavation of Tank V-9, partially melted Tanks V-1 and V-3, the fractured ISV monolith, and the surrounding contaminated soil.

- Transport and dispose of the waste forms at the ICDF (vitrified material, contaminated soil, stabilized liquids, cemented SGAC housings, and miscellaneous debris waste, including the empty tank shells and used equipment) or off-Site (the cemented GAC housings).

Detailed descriptions of the steps in these groupings are provided in Appendix F. A detailed equipment list for the proposed ISV operation is shown in Appendix D.

3.4.4   Waste Volumes and Disposal

The total volume of primary waste produced by the Planer-ISV process is 2,250 m^3. Included in this volume are 14.8 m^3 of solidified decant liquid, 165 m^3 of vitrified waste form, 2.2 m^3 of metal piping and tank shells, and 2,068 m^3 of contaminated soil. The vitrified waste form will be disposed of at the ICDF, along with the metal remnants of Tanks V-1 and V-3 and the remaining volume of contaminated soil that was not vitrified by the ISV process. Plans are to perform waste disposal approximately one year after vitrification is complete to allow sufficient time (6-12 months) for the vitrified waste form to cool.

The total volume of secondary waste expected to be produced by the complete ISV process is 123 m^3. This includes a disposed equipment volume of 83.9 m^3, a solidified condensate volume of 34.2 m^3, 2.3 m^3 of GAC, 2.0 m^3 of SGAC, and 0.5 m^3 of macroencapsulated HEPA filters. The secondary waste volume is based on the assumption that all equipment coming in contact with the tank waste and off-gas will have to be disposed of as radioactive waste. In addition, it is assumed that there will be no consolidation of the waste by placement in containers or cutting or crushing. The actual secondary waste

volume associated with this process can be substantially reduced if efforts are made to recover equipment (via D&D operations) and if actual waste can be consolidated, cut, or crushed before disposal.

3.4.5 Disposition Pathways

All waste generated as a function of this technology will be disposed of at an approved TSDF. Figure 10 provides a visual summary of the waste distribution for each component. Table 5 summarizes the volumes of waste materials expected from ISV.
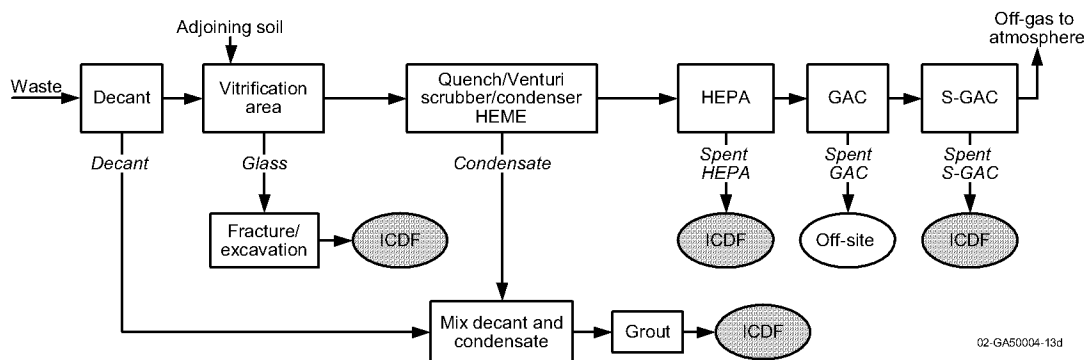

Figure 10. Summary of ISV waste distribution.

3.5 Ex Situ Vitrification

3.5.1 ESV Overview

Figure 11 is the PFD for the proposed ESV alternative. The PFD is numbered and lettered to identify the major ESV components and the subcomponents associated with each major component to correspond with the detailed mass balance for ESV (see Appendix C). A summary mass balance for ESV, showing key constituents and CFTs at major points in the process is in Section 3.5.2.

As previously described, the proposed ESV technology under consideration is a batch vitrification process, similar in concept to ICV practiced by AMEC Earth and Environmental.

As with ISV, decanting is used to remove as much liquid from the tanks as possible before vitrifying the contents. Based on the mass balances of the V-tank contents, it appears that the sludge phase alone in each of the tanks contains 58-72% liquid. There should be sufficient liquid available to slurry and remove all of the tank contents. Furthermore, the contaminant concentration in each supernatant phase does not require vitrification, and the large quantities of liquid would only increase the vitrification duration and power requirements.

ESV will require significant radiation shielding for the waste transfer system, vitrification unit(s), containment hood, and the off-gas subsystem up through the first HEPA filter. Remote or semi-remote operating methods will also be required in these areas. Storage, handling, and transportation of the vitrified waste containers may also require shielding and semi-remote operating methods.

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Table 5. Summary of waste types, volumes, expected treatments, and expected disposition for ISV.

| Generated Waste Type	Volume	Expected Treatment	Expected Disposition
PRIMARY WASTE	**2250 m³ TOTAL**		
Grouted Decant Solution (Item 3 in PFD)	12 m³ unstabilized, 14.8 m³ stabilized	Solidify w/ Aquaset, after GAC filtration	ICDF (71 55-gallon drums)
Glassified Waste Form (Item 6 in PFD)	165 m³ (includes 0.95 m³ of metal, 0.31 m³ of phosphate, and 164 m³ of vitrified waste form)	Fractured vitrified waste form in place, then excavated. Phosphate material will be packaged in two 55-gallon drums.	ICDF, w/o packaging, for vitrified waste form and metal debris ICDF (two 55-gal drums) for phosphate material
Contaminated Soil/tank AOC	2070 m³ (includes 2068 m³ of soil, 0.61 m³ of tank shells & 1.6 m³ of piping)	Excavated (no treatment)	ICDF (w/o packaging)
SECONDARY WASTE	**123 m³ TOTAL**		
GAC Decant Filter (Item 2 in PFD)	0.33 m³	Cement with Concrete, within filter housing, then macroencapsulate)	Envirocare
Grouted Condensate Solution (Item 7 in PFD)	27.9 m³ unstabilized, 34.2 m³ stabilized	Solidify w/ Aquaset	ICDF (157 55-gallon drums, plus the filled Tank V-9 shell)
Spent HEPA Filters (Item 8 in PFDs)	0.45 m³	Macroencapsulation for Disposal	ICDF (four HEPA filters)
GAC Filters (Item 9 in PFD)	2.0 m³	Macroencapsulation for Disposal	Envirocare
SGAC Filter (Item 10 in PFD)	2.0 m³	Macroencapsulation for Disposal	ICDF
Used PPE, consumable materials, non-recoverable equipment	83.9 m³	Macroencapsulation for Disposal (as needed)	ICDF (Assume twelve 10 yd³ waste boxes)
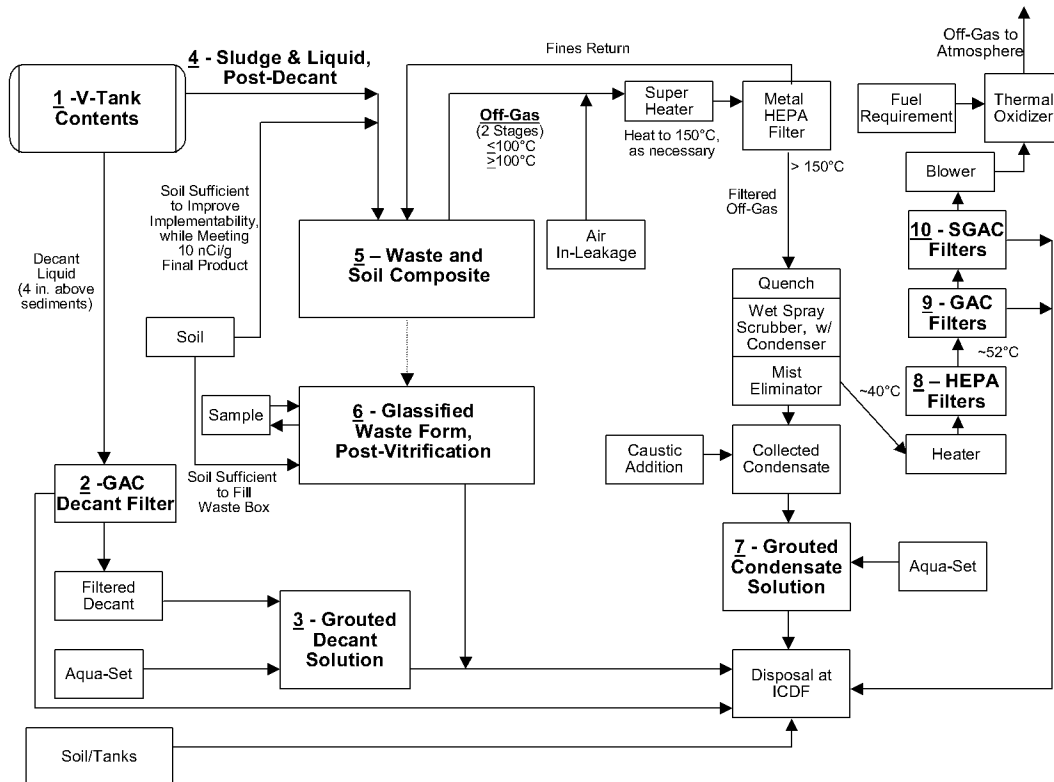
Figure 11. Ex situ vitrification with on-Site disposal/off-gas treatment process flow diagram.

Following decanting, the liquid and sludge phases of the four V-tanks will be sequentially transferred into six 20-yd^3 (15.3-m^3 roll-off boxes that have been lined with refractory material and partially filled with soil and starter path material). The roll-off boxes will then be vitrified, two boxes at a time within a single melt operation.

The total volume of refractory material present in each roll-off box is expected to be 6 m^3. The refractory material will consist of insulating boards and silica sand used to line the bottom and sides of each roll-off box. Sufficient soil is added to the ESV system to ensure safe operation and to lower radiation levels, which also ensures that the final waste form will meet the ICDF disposal WAC.

The total volume of sludge and soil to be added to each roll-off box is not expected to exceed 6 m^3, before batch ESV processing. However, the high volume of water still present in the combined soil and sludge is expected to result in a densification of over 67%. Therefore, additional soil will be added, following ESV processing (and before ICDF disposal).

The sludge can be placed directly on the added soil without mixing. The excess liquid in the sludge will simply be absorbed into the soil matrix. When placing the tank sludge on the soil, care should be taken to minimize disturbance of the preplaced graphite starter path material.

The tank contents will be slurried and removed using a jet mixing system manufactured by AEA Technologies (or equivalent type of mixing system). This type of system is expected to suspend and remove nearly all of the tank heels, even densely settled solids.

The starter paths to be preplaced within each roll-off box (along with the soil) consist of a layer of graphite flake and glass frit, placed within 1-ft of the top of the prefilled soil layer in each roll-off box. Each roll-off box will contain two vertical graphite electrode sections inserted through the starter paths to provide electrical continuity between electrodes. Thermocouples placed with the refractory material will line the inner edges of the refractory material in each roll-off box to verify completion of the melting process.

After adding the required amount of tank sludge to each of two roll-off boxes, the boxes will be rolled into the off-gas containment hood on tracks that pass through the hood. The electrodes will be connected to the power transformers, the hood opening will be sealed, and the pipe from the containment hood to the off-gas system will be attached. Based on previous conventional ISV and batch ESV processes, it is expected that the V-tank contents can be melted with added soil at an efficiency of approximately 1.0 kWh/kg of material, with a 60-70% volume reduction occurring in the melt (depending on the water content per batch).

It is expected to take less than 48 hours to process two roll-off boxes, each filled with 6 m^3 of sludge and soil. Following melting, both roll-off boxes will remain in the hood for approximately 24 hours for cooling and residual off-gassing. During this time, two new roll-off boxes will be refractory-lined, have thermocouples installed, be filled with their designated volumes of soil and tank sludge, and have starter paths preplaced (before sludge addition). Upon completing the 24 hour cooling period, a crane will be used to lift the entire hood containment structure from over the partially cooled roll-off boxes containing vitrified waste. The containment hood will then be placed over the top of the newly prepared roll-off boxes (making sure to connect the electrodes to power, before lowering the hood over the roll-off boxes). A new batch melting period will then be initiated. A total of three melts will be used to vitrify the entire V-tank contents (with added soil) in six 20-yd^3 roll-off boxes. Total vitrification time is less than 144 hours.

Based on mass balance calculations in Appendix C, portions of the various V-tank sludges may have to be combined with other tank sludges as part of each batch ESV. Current estimates are that the sludge from Tank V-1 will fill approximately 1.5 roll-off boxes, the sludge from Tank V-2 will fill 0.75 roll-off boxes, the sludge from Tank V-3 will fill 1.75 roll-off boxes, and the sludge from Tank V-9 will fill 2 roll-off boxes.

Based on previous conventional ESV melts, the off-gas will reach temperatures up to 350°C during batch ESV processing. The off-gas will contain carbon monoxide, hydrogen chloride, mercury, VOCs, pyrolyzed organics, entrained radionuclides, and cesium. The rate of off-gas release is expected to vary from 2.0–4.5 m^3/min during the initial part of the process (when liquid vapor and VOCs are released) to less than 1 m^3/min during the later phases of the process (when hydrogen chloride, mercury, and carbon monoxide are released). To handle the varying rates of off-gas release, the ESV off-gas system has been designed with a 50 std m^3/min (1,800 scfm) blower and in-leakage to prevent loss of hood vacuum during the ESV process. Although such a blower may be oversized, it serves a dual purpose by also keeping the walls of the hood relatively cool.

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To capture radionuclides, the off-gas system has two stages of HEPA filtration (with the first stage at the beginning of the off-gas train to minimize contamination of the rest of the system and the second stage near the end for backup purposes). To capture hydrogen chloride, the off-gas system is equipped with a quench tower, a two-stage venturi scrubber/condenser, and a high efficiency mist eliminator. The off-gas system is equipped with GAC and SGAC filters to capture VOCs and mercury. For carbon monoxide removal, a propane-fueled thermal oxidizer is placed downstream of the off-gas blower.

After ESV, the waste forms within each roll-off box will be allowed to cool, and then additional soil will be added to completely fill the box. Each roll-off box, containing the refractory lining, vitrified waste form, and soil fill, will be disposed of at the ICDF as a complete waste package. The decanted liquid and process condensate collected will be treated by processing through a filter train containing filters designed to remove any organic contaminants from the liquids[b], prior to their stabilization (with Aquaset) to ensure the liquid, once solidified/stabilized, will meet LDRs. The liquid is placed in 55-gal. drums as it exits the filter train and sampled according to an approved field sampling plan. After sample results verify that LDRs will be met, the liquid will be solidified with Aquaset, then disposed of at the ICDF. The GAC filters will be macroencapsulated in their housings, then sent off-Site for disposal (due to the expected organic content). The SGAC filters will also be cemented in their housings, macroencapsulated, and disposed of at the ICDF. (See the last bullet of Section 2.1.) Used HEPA filters will also be macroencapsulated and disposed of at the ICDF. Any contaminated equipment, consumable materials, nonrecoverable equipment, and PPE that cannot be decontaminated for clean release will be disposed of as debris at the ICDF.

The V-tank AOC will then be excavated to remove the empty tanks and contaminated soil. Plasma-arc cutting will be used to size the tanks into metal shells for disposal as debris at the ICDF. Tank V-9 will be filled with treated decant or condensate liquid, then solidified with Aquaset.

3.5.2 Mass Balance Summary

A summary mass balance table for the proposed ESV remediation system is shown in Table 6. The table is a summary of the more detailed mass balance presented in Appendix C. The summary table contains information about the fate of specific contaminants for treatment within each major component, as well as the total amount of liquid, solids, and added materials within each major component of the proposed system.

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b. According to mass balance projections, the collected process condensate should be able to bypass the carbon filter adsorption of organics and be stabilized directly with the selected agent.

Table 6. Summary mass balance for the ESV process.

Stream Name	V-Tank Contents	GAC Decant Filter	Grouted Decant Solution	Sludge & Liquid Post-Decant	Decanted Sludge & Added Soil, Pre-Vitrification	Glassified Waste Form, Post-Vitrification	Grouted Condensate Solution	HEPA Filters	GAC Filter	SGAC Filter
Stream Number	1	2	3	4	5	6	7	8	9	10
Volume (L)	2.24E+04	2.06E-01	1.47E+04	1.03E+04	3.23E-04	1.17E+04	6.99E+03	4.53E+02	1.82E+03	1.82E+03
Mass (kg)	2.26E+04	8.25E-00	1.69E+04	1.06E+04	5.04E-04	3.15E+04	8.01E+03	1.51E+01	7.27E+02	7.27E+02
Component										
Inorganics										
Cd (mg/kg)	1.36E+02	0	3.09E-02	4.32E+01	9.06E+00	0	5.68E-03	1.12E-02	0	0
Chlorides (mg/kg)	1.65E+02	0	9.42E+01	1.42E+02	2.97E+01	0	2.57E+02	0	0	0
Cr (mg/kg)	5.96E+02	0	9.82E-02	1.28E+03	3.23E-02	5.18E+02	0	0	0	0
Hg (mg/kg)	2.59E+02	trace	7.99E-02	5.55E+02	1.16E-02	0	trace	trace	trace	8.05E+03
Pb (mg/kg)	2.82E+02	0	1.82E-01	6.03E+02	1.26E+02	2.02E+02	trace	trace	0	0
VOCs										
PCE (mg/kg)	2.37E+02	4.27E+02	0	5.07E+02	1.06E-02	0	0	0	7.36E+03	trace
TCA (mg/kg)	1.05E+02	1.22E+03	0	2.23E+02	4.67E+01	0	0	0	3.23E+03	trace
TCE (mg/kg)	8.54E+02	8.97E+03	0	1.82E+03	3.82E+02	0	0	0	2.65E+04	trace
SVOCs										
BEHP (mg/kg)	9.10E+02	1.53E+02	0	1.95E+03	4.08E-02	0	0	0	trace	trace
Aroclor-1260 (mg/kg)	3.59E+01	1.45E+02	0	7.68E+01	1.61E+01	0	0	0	trace	trace
Radionuclides										
Cs-137 (nCi/g)	1.98E+03	0	4.13E+00	4.23E+03	8.86E-02	1.42E+03	1.67E-04	trace	0	0
Sr-90 (nCi/g)	3.68E+03	0	7.74E+00	7.87E+03	1.65E+03	2.64E+03	1.04E-04	trace	0	0
TRU (nCi/g)	8.57E+00	0	3.03E-03	1.84E+01	3.85E+00	6.16E+00	2.42E-07	trace	0	0
Other										
Total Carbon (mg/kg)	2.53E+04	8.90E-04	0	5.42E+04	2.41E+04	0	0	0	trace	

*Chlorides shown in the Grouted Condensate Solution include those derived from PCB destruction.

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3.5.3   Major Process Steps

There are a total of thirteen major processes, or components, associated with the proposed ESV process. These major components include:

- Decanting excess supernatant from all four V-tanks before performing ex situ vitrification.

- Preparing the roll-off boxes for sludge addition (lining with refractory material and adding soil and starter path).

- Placing shielding and contamination control equipment around the roll-off boxes before sludge addition.

- Sequentially pumping the liquid sediment phase and residual supernatant from all four V-tanks into refractory-lined, 20-yd^3 roll-off boxes partially filled with soil. Pumping will be performed using the AEA Jet Mixing System (or equivalent), and will be done in a manner that flows the pumped sludge over the top of the partially filled soil and preplaced starter path, without mixing the soil and the sludge.

- Placing the roll-off boxes into the off-gas collection hood two at a time, connecting the electrodes to the supplied power, and processing the roll-off box waste contents using batch ESV technology.

- Collection and HEPA filtration of the off-gas resulting from the batch ESV process before entering the off-gas treatment system.

- Quenching, 2-stage scrubbing, condensation, and mist elimination of the off-gas stream to remove acid gases from the off-gas.

- GAC and SGAC filtration of the cooled off-gas stream to remove residual organics and mercury.

- Polishing the treated off-gas using a propane-fueled thermal oxidizer to guarantee complete destruction of the organic vapors (those not captured by the GAC filter) and convert carbon monoxide to carbon dioxide before release to the environment.

- GAC filtration of the decanted supernatant (to remove residual organics from the liquids), followed by 55-gal. drum containerization of the decanted supernatant and collected condensate liquids, and stabilization of the liquids using Aquaset or an equivalent liquid absorbent. The GAC and SGAC beds will be characterized after treatment of the V-tank waste to determine the need for treatment prior to disposal. (See last bullet of Section 2.1.)

- Excavation of the empty V-tanks and surrounding contaminated soil.

- Transportation and disposal of the residual waste forms at the ICDF (roll-off boxes containing vitrified material, contaminated soil, stabilized liquids, cemented SGAC housings, and miscellaneous debris waste, including the empty tank shells and used equipment) or off-Site (the cemented GAC housings).

Detailed descriptions of each of these major components, as well as their subcomponents and process descriptions, are provided in Appendix F. They correspond to the process flow diagram shown in Figure 11 and the mass balance calculations included in Table 6 and Appendix C. A detailed equipment list for the proposed ESV operation is presented in Appendix E.

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3.5.4   Waste Volumes and Disposition

The total volume of primary waste produced by the ESV process is 2,427 m³. Included in this volume is 14.8 m³ of solidified decant, 69 m³ of roll-off boxes, including vitrified waste form, 3.1 m³ of metal piping and tank shells, and 2,340 m³ of contaminated soil. The vitrified waste form will be disposed of at the ICDF, along with the metal remnants of Tanks V-1 and V-3 and the remaining volume of contaminated soil that was not vitrified by the ESV process.

The total volume of secondary waste expected to be produced by the complete ESV process is 88 m³. This includes a disposed equipment volume of 76.4 m³, a solidified condensate volume of 7.1 m³, 2.1 m³ of GAC, 1.8 m³ of SGAC, and 0.5 m³ of macroencapsulated HEPA filters. The secondary waste volume is based on the assumption that all equipment coming in contact with the tank waste and off-gas will have to be disposed of as radioactive-waste. In addition, it is assumed that there will be no consolidation of the waste by placement in containers or cutting or crushing. The actual secondary waste volume associated with this process can be substantially reduced if efforts are made to recover equipment (via D&D operations), and if actual waste can be consolidated, cut, or crushed before disposal.

3.5.5   Disposition Pathways

All waste generated as a function of this technology will be disposed of at an approved TSDF. Figure 12 provides a visual summary of the waste distribution for each component. Table 7 provides a summary of the total volume of waste materials expected to be generated by the batch ESV process.
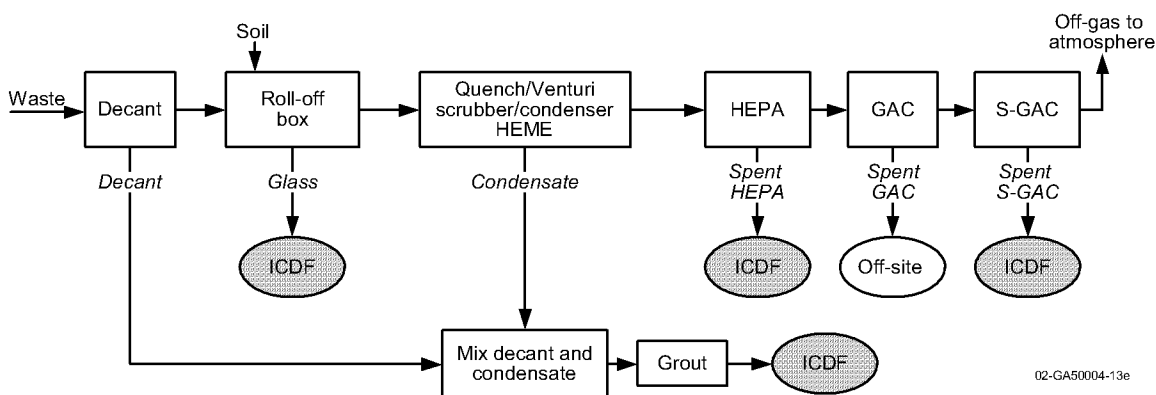

Figure 12. Summary of ESV alternative waste disposition.

Table 7. Summary of waste types, volumes, expected treatments, and expected disposition for ESV.

Generated Waste Type	Volume	Expected Treatment	Expected Disposition
PRIMARY WASTE	**2427 m³ TOTAL**		
Grouted Decant Solution (Item 3 in PFD)	12 m³ unstabilized, 14.8 m³ stabilized	Solidify w/ Aquaset, after GAC filtration	ICDF (71 55-gallon drums)
Roll-Off Boxes, Containing Glassified Waste Form (Item 6 in PFD)	Total volume of 68.9 m³, (includes 36 m³ of refractory material, 11.7 m³ of vitrified waste form, and 21.2 m³ of contaminated soil)	No further treatment required. Soil is added to fill the void left from subsidence, during the batch ESV process.	ICDF (Six roll-off boxes)
Contaminated Soil/tank AOC	2343 m³ (includes 2340 m³ of soil, 1.5 m³ of tank shell, and 1.6 m³ of misc. piping)	Excavated (no treatment)	ICDF (w/o packaging)
SECONDARY WASTE	**88 m³ TOTAL**		
GAC Decant Filters (Item 2 in PFD)	0.33 m³	Cement with Concrete, within filter housing, then macroencapsulate)	Envirocare
Grouted Condensate Solution (Item 7 in PFD)	5.7 m³ unstabilized, 7.1 m³ stabilized	Solidify w/ Aquaset	ICDF (27 55-gallon drums, plus the filled Tank V-9 shell)
Spent HEPA Filters (Item 8 in PFD)	0.45 m³	Macroencapsulation for Disposal	ICDF (four HEPA filters)
GAC Filters (Item 9 in PFD)	1.8 m³	Macroencapsulation for Disposal	Envirocare
SGAC Filters (Item 10 in PFD)	1.8 m³	Macroencapsulation for Disposal	ICDF
Used PPE, consumable materials, non-recoverable equipment	76.4 m³	Macroencapsulation for Disposal (as needed)	ICDF (Assume twelve 10 yd³ waste boxes)

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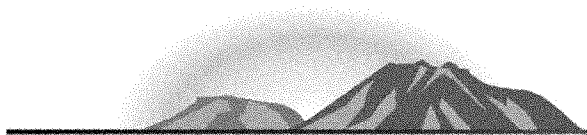
4. THERMAL DESORPTION

Thermal Desorption (TD), typically used as a first-step separation process in a treatment train, removes volatile organics and volatile metals such as mercury from solids and liquids by raising the temperature of the waste to a level sufficiently high enough to volatilize contaminants and transfer them to the off-gas stream. After the various hazardous constituents are separated into discrete waste streams, these relatively homogenous wastes can be easily treated. Various thermal desorption technologies employ differing combinations of temperature, residence times, feed mixing, and vacuum to heat the material and transfer the contaminants to the off-gas stream. Several classes of thermal desorber units have emerged, including indirect- and direct-heated units, units operated at atmospheric pressure, and those operating under vacuum. The thermal desorption system that will be employed for treatment of the V-tank liquid and sludge waste will be a vacuum thermal desorption unit, which is an indirectly heated rotary kiln operated under vacuum.

There are significant benefits to operating under a vacuum. Specifically, operating at low pressures allows the use of lower temperatures to achieve the same level of organic materials removal. Also, operating in an inert (nonoxidizing) environment provides little opportunity for organic destruction to take place, thus, prohibiting the generation of dioxins and furans. TD also has regulatory acceptance under RCRA and TSCA agencies. When followed by condensation, TD meets the LDR standard for treatment of high mercury category wastes (40 CFR 268.40), commonly referred to as roasting or retorting mercury (RMERC). TD is defined as a "retort" unit for RCRA treatment of high-mercury category wastes, and TSCA regulations provide for operation without a permit for decontamination processes that include distillation. These benefits make TD a viable technology.

TD has been successfully used to separate and remove mercury, volatile organics, and PCBs from the following hazardous and TSCA cleanup sites across the nation.

- US Copper Smelter in Claypool, Arizona—mercury has been thermally desorbed from 550 tons of soil and subsequently recycled

- Brookhaven National Laboratory—a bench scale treatability study was successfully performed on dioxin and furan contaminated mixed incinerator ash, a low level waste

- DOE Rocky Flats Facility—a pilot scale treatability study was successfully performed on mixed low-level waste (PCBs, PCE, and BEHP)

- Chlor-Alkali Plant in Houston, Texas—20 tons of mercury contaminated sludge were treated

- Rocky Flats Facility in Golden, Colorado—3,800 yd^3 of mixed waste soil contaminated with chlorinated solvents were treated (Technical Resource Document on Permitting Vacuum Thermal Desorption Treatment Processes for TRU and Mixed Waste Treatment)

- Longhorn Army Ammunition Plant, Burning Ground No. 3 at Karnack, Texas—more than 51,000 tons of VOC (methylene chloride, TCE, etc.) soil was treated (U.S. Army Corps of Engineers Hazardous, Toxic, Radioactive Waste Center of Expertise)

- McKin Company Superfund Site at Gray, Maine—more than 11,500 tons of VOC (i.e., TCE) contaminated soil were treated

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- Outboard Marine Corporation Superfund Site at Waukegan Harbor, Illinois—12,755 tons of PCB contaminated soil were treated (EPA 2002).

As shown in the above examples, TD is a mature technology that is well suited for treating the V-tanks' liquid and sludge. However, in radiological applications, routine TD operations are somewhat more complex due to the requirement to minimize release of contaminated particles from the dry product. This adds significant complexity to the typical materials handling system designs.

Three alternatives have been identified for vacuum TD treatment of the V-tanks liquid and sludge. The alternatives being considered are:

- Alternative 1—on-Site liquid and sludge treatment and containerization, off-Site treatment of secondary waste (off-gas residuals), and on-Site disposal of residuals (TD on/off-Site)

- Alternative 2—on-Site liquid and sludge treatment, containerization, and treatment of secondary waste (off-gas residuals), with on-Site disposal of residuals (TD on-Site)

- Alternative 3—on-Site liquid and sludge treatment and containerization, with off-Site treatment of secondary waste (off-gas residuals), interim storage, and disposal of residuals (TD off-Site).

In the TD on/off site, and off-site alternatives, the organic constituents are not destroyed, thus compliance with MACT requirements is not necessary. However, in the TD on-site alternative, a thermal oxidation step is included, thus the off-gas system is designed to meet MACT requirements.

4.1 Key Assumptions

Key assumptions specific to regulatory compliance, process efficiencies, analytical data, etc., have been identified and included. The following is a list of the developed assumptions:

- Equipment must use available TAN utilities (electrical, etc.)

- Equipment transferring V-tanks' waste and liquid residuals will have secondary containment where required

- The tank contents removal system shall be capable of both decanting liquid (without sludge disturbance) and tank homogenization [NOTE: These two operations use different major equipment.]

- If waste from Tank V-9 is treated as a separate waste stream and must be "retorted," the thermal desorption processes will be viewed as meeting the retort treatment standard

- A trial burn will not be required for implementation and/or waste treatment

- The final waste form concentrations (desorbed bottoms, grouted wastes, etc.), following all the necessary treatments, will be used in establishing the final contaminants for treatment concentrations

- HEPA filters will be macroencapsulated (i.e., containerized and encased in a non-leachable media like concrete) on-Site prior to disposal at an approved TSDF (ICDF, Envirocare, etc.)

- The activated carbon beds will be treated and disposed of on-Site (ICDF) or shipped directly to an approved TSDF (Envirocare, etc.) for treatment and disposal

- Scrubber and condenser waste solutions will be treated to meet LDR standards either on-Site or off-Site prior to disposal.

4.2   Technical and Functional Requirements

Technical and functional requirements identified for each of the major units of operation are summarized below.

4.2.1   Waste Feed System

The waste feed system shall be:

- Capable of removing tank contents without the use of additional uncontaminated water

- Capable of slurrying the settled sludge into the liquid layer so both are removed from the tank during transfer to the TD unit

- Capable of feeding slurried waste directly to the TD unit in batches (100 gal./batch ±10 gal., 200 gal./batch ±10 gal., etc.)

- Capable of being back flushed to the originating tank

- Capable of real-time monitoring (pressure, flow, etc.).

4.2.2   Soil Feed System

The soil feed system shall be:

- Capable of screening and feeding soil (≤ 2" in diameter) directly to the TD unit through valved or flanged ports

- Capable of feeding soil in batches (e.g., 870 gal./batch ±5 gal.)

- Capable of preventing spurious dust emissions from reaching the worker environment.

4.2.3   Operating Control System

The operating control system shall be:

- Capable of operating by using a secondary (backup) power source (i.e., electric generator)

- Capable of controlling the temperature and environment to ensure accurate and continued operations

- Capable of controlling unit operations so that operating control limits are met and maintained.

4.2.4   Thermal Desorption Unit

The thermal desorption unit shall be:

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- Capable of indirect heating using propane or natural gas as a heat source

- Capable of receiving in-process off-gas fines as removed from the metal filter

- Capable of operating routinely at or below 400°C

- Capable of operating under a vacuum (≤40 mm Hg) and utilizing process monitoring to switch between a non-vacuum system (early stages/low temperatures) and a vacuum-system at the appropriate time.

- Capable of treating up to 970 gallons (5,310 kg) per batch of feed, comprised of waste slurry and soil

- Capable of feed mixing (vessel rotation, internal paddles, etc.) during thermal desorption operation

- Capable of transferring hot treated solids (bottoms) into a bottoms hopper.

4.2.5 Bottoms Transfer System

The bottoms transfer system shall be:

- Capable of receiving and holding entire batches (970 gal. ±5 gal.) of hot (300°C) bottoms

- Capable of transferring treated solids (bottoms) from the bottoms hopper directly to individual or palletized containers (roll-offs, 55-gallon drums, etc.) while the TD unit is operating

- Capable of operating routinely inside an enclosure with HEPA air filtration while receiving dry residuals from the TD vessel and transferring/loading hot bottoms into individual or palletized containers

- Capable of providing for container closure while containers are located inside the enclosure

- Capable of controlling container fill rates and volumes so that no container can be overfilled.

4.2.6 Off-Gas System

The off-gas system shall be:

- Capable of removing and changing components (HEPA filters, GAC filters, etc.) during daily operation

- Capable of providing secondary, back-up air filtration units (redundant HEPA filters, GAC filters, etc.)

- Capable of process monitoring (organics, inorganics, participate, etc.) between filtration units (HEPA filters, GAC filters, etc.)

- Capable of filtering and removing volatile, semi-volatile, and inorganic constituents from the off-gas (condenser, scrubber, activated carbon filters, etc.)

- Capable of avoiding condensation of water vapor in the system except in the condenser unit

- Capable of separating fines entrained in the TD unit off-gas and returning them to the TD unit

- Capable of withstanding temperatures up to 400°C

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- Capable of handling and transferring the airflow and moisture content to the condenser

- Capable of handling and storing condenser and scrubber waste solutions

- Capable of transferring (gravity feed, pumping, etc.) waste solutions to containers or holding tanks.

4.3   Major Components and Process Steps

Process and equipment descriptions have been provided at a summary level in the following sections. They correspond with the process flow diagrams and summary mass balance tables included in Sections 4.4, 4.5, and 4.6, and with the detailed mass balance calculations included in Appendix C.

TD is unique, compared to other waste treatment technologies, because it separates the hazardous constituents into separate and distinct waste streams (bottoms, condenser and scrubber solutions, GAC beds, etc.) that will then be treated using proven methodologies. Tank V-9 fails toxicity characteristic leaching procedure (TCLP) for mercury and exceeds 260 mg/kg (total metals). In the event that Tank V-9 is required to be treated separately, the technology-based treatment standard is "RMERC" (retort) would be applied. TD is a technology that is assumed to meet this requirement and therefore does not require a Determination of Equivalent Treatment by EPA. However, like each of the other proposed V-tank treatment technologies, TD will require a waiver from the state of Idaho for on-Site operations.

In this application, TD will vaporize the volatile contaminants present in the liquid and sludge and transfer them to the off-gas stream, where they will either be treated on-Site or condensed and shipped off-Site for treatment. While the volatile hazardous constituents are vaporized, the radionuclides and the non-volatile heavy metals remain in the bottoms. In order to obtain suitable processibility in Alternatives 1 and 2, enough soil will be added to each 100-gallons of waste to produce a kiln feed having only 20% moisture content. As a result of the varying moisture contents in the V-tanks (91.3, 88.8, 87.9 and 64.4% for Tanks V-1, V-2, V-3, and V-9 respectively), varying amounts of soil are required per tank. For on-Site disposal of the bottoms, soil will be added to facilitate optimum desorption operation (reduce the liquid content to avoid waste plating on the vessel walls, reduce liquid vaporization times, etc.). For off-Site disposal, bottoms will either be shipped to WIPP without treatment or shipped to NTS or Hanford after stabilization treatment. While process and equipment optimizations will likely occur later in the design process, the equipment selection, layout, and operation will be based on the process flow diagrams in this document.

Significant radiation shielding and semi-remote operating methods will be required for the materials transfer subsystems. The TD unit, off-gas subsystem up through the first HEPA filter, bottoms handling subsystem, and bottoms stabilization subsystem will require radiation shielding and require semi-remote operating methods. Radiological contamination control for the transfer of bottoms from the TD unit to a receiving vessel and from the receiving vessel into containers (including sampling, stabilization, handling, storage, and transportation activities), will be a major engineering, safety basis, and procedural challenge due to the dry, potentially very fine material.

4.3.1   Waste Feed System

Liquid and sludge waste will be removed from each of the V-tanks using the AEA fluidic jet removal system (or equivalent). This system is capable of slurring and removing the sludge and liquid layers. The AEA system circulates the sludge and liquid by drawing the material into the system charge

vessel and injecting it back into the tank at relatively high velocity. This "slurries" loose material and dislodges materials that have caked or agglomerated in the vessel to produce a relatively uniform slurry waste stream that can then be transferred in batches by diverting the charge vessel contents to the TD unit. The AEA system will be emptied back into the originating tank after each batch makeup operation and shutdown. The AEA system will be reactivated just before it is needed for another batch makeup to ensure re-suspension of any tank material that may have settled out in the interim.

4.3.2   Soil Feed System

The soil feed system will consist of a shaker table screen, a soil hopper, and a feed conveyor (i.e., screw feed system). Soil will be removed from the V-tank area or available soil piles via a front end loader, or comparable equipment, and screened to remove any particles and objects greater than two inches in diameter as it is being transferred into the soil hopper. To control dust emissions, misting will be used as required during excavation and screening. Misting contributes water that then increases processing cost, so it will only be used when necessary. The soil hopper feed system will transfer the soil to the vacuum TD vessel, where it will be mixed with the V-tanks' waste slurry as the low temperature liquid removal phase of the TD process proceeds. An enclosure will be built around the screen/hopper system to reduce industrial hazards.

4.3.3   Thermal Desorption Unit

The TD unit will be an indirect-heated, vacuum-assisted, rotary kiln capable of operating at a maximum temperature of 400°C under a high vacuum. Normal operating high temperature will be 300°C. This vacuum unit enables higher boiling point compounds to be evaporated at lower temperatures. Since most of the radioactive substances have relatively high melting and boiling points, the vacuum TD minimizes the amount of radioactive materials carried over in the off-gas as condensing gaseous species. However, radionuclides can enter the off-gas system from the particulate waste form itself, which should be minimal.

The TD unit will process material in batch sizes of up to 970 gallons of feed material per batch. A variable-speed drive will be used to adjust the rotational speed of the TD cylinder to achieve the maximum heat transfer. Nitrogen, an inert gas, will be added to displace all of the atmospheric oxygen and to ensure an inert process environment. In addition, this gas will act as the motive for carrying desorbed species from the kiln to the off-gas system. The unit will have internal paddles that turn the process material during operation. The TD unit will direct feed process residues to a hopper for transfer and drumming after each complete desorption operation. The treatment efficiency for the TD system will depend on the waste temperature and its residence at temperature. To ensure that the liquid and low and high boiling point CFTs (organics/inorganics) are efficiently removed, the TD unit will have two modes of operation—low temperature, followed by high temperature.

In the low temperature operation mode, the vessel and the process materials will be brought from ambient temperature to the boiling point of water at approximately 95°C under slight vacuum. The system will be maintained at this temperature until all moisture has been removed. In this mode, all volatile compounds are desorbed, while a portion of the heavier semi-volatile compounds begin to desorb. The volatile species (TCE, PCE, etc) will be vaporized and transferred into the off-gas system via the nitrogen carrier gas, where it will either be treated or collected for off-Site treatment. It is also estimated that

approximately 20% of the mercury may be vaporized during low temperature operations. The high temperature mode of operation will begin after the waste is dried.

The high temperature mode is the treatment stage in which the material temperatures are elevated beyond the boiling temperature of water to the target process temperature of 300°C. In this mode of operation, the system will be brought under a high vacuum pressure of 40 mm Hg (absolute) and held at the target condition for up to two hours. Under the high temperature desorption mode, all semivolatile and heavier constituents (SVOC, PCB, Hg) are desorbed into the gas stream. If the temperature is increased slowly, these compounds can be converted to vapors and removed from the retort before decomposition. It will be either treated or collected for off-Site treatment. After the retort operation is complete, the vacuum will be released and the processed materials (solids, soil, silica, lead, cadmium, radioactive isotopes) will be transferred to a bottom collection hopper for subsequent container loading.

4.3.4   Bottoms Transfer System

After TD, the bottoms residue must be transferred to a location that will not impede continued desorption operations and will allow drum loading. To do so, the TD unit will have a mechanical slide that, when opened, will allow residue to drop out and into a hopper vessel. The hopper will have a mechanical shaker device that will first dislodge, then keep solids from sticking to the hopper lining. The residue will continue to cool for a maximum of three hours inside the hopper before being distributed to approved containers (i.e., roll-offs, 55-gallon drums, etc.). All containers will be made of materials that can sustain elevated temperatures (i.e., 200°C) without structural failure. A flow meter will be installed inside the hopper trunk to measure and control waste feed distributions. Containers will be loaded and placed on wheeled pallets by a forklift for ease of removal. Containers will be sealed manually, either inside or outside the ventilated enclosure. To protect workers, an enclosure with HEPA air filtration will be installed around the bottoms transfer station. Dust mitigation controls will be available as required.

4.3.5   Stabilization System

Prior to stabilization, the residue and waste liquid from the different unit operations (desorber, condenser, scrubber, and quencher) will be containerized and sampled. Characterization will identify individual constituents and their concentrations, thus, determining the correct combination of stabilization agents (Portland Cement, grout, Aquaset, etc.). The stabilization agent and water will then be added directly to the waste containers, where they will be mixed using an "in-drum" paddle mixer. After completion of the stabilization process, the containers will be staged pending hardening and recharacterization. Recharacterization will be performed to ensure that the recipe used and the final waste form meets the WAC of the predetermined TSDF (ICDF, NTS, etc.). Once it has been determined that the waste meets the WAC, containers will be staged pending shipment for disposal. This entire system, including surge capacity for incoming wastes, and stabilized solids awaiting final characterization will require specialized design to meet requirements due to radiological contamination.

4.3.6   Off-Gas System (NonMACT Compliant)

The off-gas system has been divided into nonMACT compliant and MACT compliant categories. The following summaries are for the nonMACT compliant off-gas system.

Super Heater

The off-gas leaving the thermal desorber will be heated in the super heater to 300°C during both low and high temperature operation modes to prevent water or any organics from condensing in the downstream metal filter and vacuum pump. An electrically heated super heater will be used to elevate and maintain the prescribed operating temperature. The temperature of the off-gas exiting the metal filter controls the heater. The outlet temperature must be maintained above the dew point of the gas system.

Sintered Metal Filter

The sintered metal filter immediately follows the super heater, and it is used to remove the entrained soil and particle fines from the off-gas stream. The filter uses metal screens to separate particles greater than two microns from the off-gas. Fines that have deposited on the screens will be blown back (dislodged) using pressurized air between batches to avoid any significant accumulation of the material (which could result in a higher pressure drop) on the filter screen. The metal filter will be capable of operating at temperatures up to 400°C.

Vacuum Pump

The vacuum pump following the metal filter will be used to maintain pressure at 650 mm Hg below ambient pressure on the TD vessel during low temperature operation, the interval where most of the liquid is evaporated. The vacuum pump will be used to maintain the pressure at about 40 mm Hg (absolute pressure) during high temperature operations to remove high boiling point organics. Under these conditions, off-gas at approximately 30 scfm will flow through the pump to the down stream components. The vacuum pump will be capable of operating at temperatures up to 400°C.

Condenser

A condenser system is commonly used in a thermal process where thermal oxidation is not appropriate. The condenser is used to reduce off-gas temperature for removal of volatile and inorganic constituents. It will be operated from 25 to 90°C to ensure that the appropriate amounts of liquid and VOCs (i.e., PCE, TCE. etc., approximately 99.9% of the off-gas) are condensed out of the off-gas. The condensed solutions generated during the low temperature operations will be collected in a surge tank for storage. During high temperature operations, nitrogen will be added upstream to cool the off-gas to 150°C and the condenser will be by-passed to the downstream filters (GAC, SGAC, & HEPA) where the mercury and SVOCs (i.e., PCB, BEHP, etc.) will be collected and treated. It is expected that the majority of condensed waste (>90%) will be collected during low temperature operations.

Surge Tank(s)

There is one surge tank in the condenser system to hold condensed wastes pending containerization and shipment for treatment. It will be made from carbon steel or high-density polyethylene, will store up to 4,000 gallons, and will have secondary containment (tank and piping). Waste will be pumped to containers (1,000-gal. high-integrity containers, etc.) for storage pending treatment and disposal (on-Site or off-Site).

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Mist Eliminator

The off-gas from the condenser will enter the mist eliminator (ME) vessel, which will remove the remainder of the liquid entrained in the off-gas. Entrained liquid will be removed by a stainless steel wire mesh, collected in the bottom of the ME, and drained into the low temperature surge tank. The ME will be sized for a large gas flow rate. The reduced flow through the oversized ME increases the residence time and, therefore, increases the efficiency of the unit. The residual liquid removed will be pumped to the low-temperature holding tank for treatment and disposal.

Heater

The off-gas leaving the mist eliminator, which will have cooled slightly, will be reheated using an electrical heater to 150°C to prevent condensation in the HEPA filters, located downstream. The temperature of the off-gas exiting the HEPA filters will control the heater. The HEPA filter outlet temperature must be maintained above the dew point of the gas stream.

Activated Carbon/Sulfur Absorbent

The GAC beds (sulfur and non-sulfur impregnated) remove any residual organics, PCBs, and elemental mercury remaining in the off-gas after scrubbing or condensing operations. After these constituents are removed, the off-gas is routed to a blower that discharges to the atmosphere.

There are two parallel trains of three GAC beds in series. The first GAC bed in each train is the primary bed, and the second and third are used as polishing beds. The primary bed is granular activated carbon for organics removal. The polishing beds are sulfur impregnated granulated activated carbon (i.e., Mersorb) for mercury removal. Mercury loading on the SGAC filters will be 10 – 15 wt%. The GAC bed is designed for a two second residence time with the assumption that the required DRE for mercury will be achieved for the duration of V-tank processing. When the primary or secondary beds in a train are saturated, the train will be taken out of service and the saturated beds replaced. VOC and mercury concentrations will be monitored following each bed. In the event VOC and/or mercury are detected, valves will automatically route off-gas through the other, parallel train.

The GAC beds will be shipped to an off-Site TSDF (Envirocare, Permafix, etc.) for treatment and disposal, due to the VOC concentrations present after use. SGAC beds will be macroencapsulated and disposed of at the ICDF as debris.

HEPA Filter(s)

The off-gas stream flows through one bank of HEPA filters prior to entering the blower for discharge. They are placed after the GAC filters to remove aerosolized activated carbon and to prevent it from reaching the environment. The primary bank consists of three HEPA filters in series. Parallel to the primary bank is a back-up bank of three HEPA filters that can be brought on line in the event the filter train becomes blocked. The individual HEPA filters have dioctyl phthalate test ports between them for testing the installed condition of the filters. HEPA filtration will continue during waste treatment operations. The HEPA filters are standard 24 x 24-in. filters with a nominal capacity of 1,000 cfm. The capacity of the bank is then roughly 3,000 cfm.

Blower

The off-gas blower has a capacity of 1,250 scfm. It will be manufactured of materials that are compatible with air constituents to prevent corrosion inside the blower and ductwork. The blower will be operated while waste is being treated and handled.

4.3.7   Off-Gas System (MACT Compliant)

The off-gas system has been divided into nonMACT compliant and MACT compliant categories. The following summaries are for the MACT compliant off-gas system.

Super Heater

The off-gas leaving the thermal desorber will be heated in the super heater up to 300°C during both low and high temperature operation modes to prevent liquid or any organics from condensing in the downstream metal filter and vacuum pump. An electrically heated super heater will be used to elevate and maintain the prescribed operating temperature. The temperature of the off-gas exiting the metal filter controls the heater. The outlet temperature must be maintained above the dew point of the gas system.

Sintered Metal Filter

The sintered metal filter immediately follows the super heater and is used to remove the entrained soil and particle fines from the off-gas stream. The filter uses metal screens to separate particles greater than two microns from the off-gas. Fines that have deposited on the screens will be blown back (dislodged) using pressurized air between batches to avoid any significant accumulation of the material (which could result in a higher pressure drop) on the filter screen. The metal filter will be capable of operating at temperatures up to 400°C.

Vacuum Pump

The vacuum pump following the metal filter will be used to maintain pressure at 650 mm Hg below ambient pressure on the TD vessel during low temperature operation, the interval where most of the liquid is evaporated. The vacuum pump will be used to maintain the pressure at about 40 mm Hg (absolute pressure) during high temperature operations to remove high boiling point organics. Under these conditions, off-gas at approximately 30 scfm will flow through the pump to the down stream components. The vacuum pump will be capable of operating at temperatures up to 400°C.

Flameless Thermal Oxidizer

Thermal oxidizers cause organic compounds in the emissions stream to react with available oxygen producing oxides of the pollutant constituents. For typical organic compound mixtures of halogenated and nonhalogenated organics, the predominant oxidation byproducts are carbon dioxide, water vapor, and HCl. The thermal oxidizer for this application will be skid mounted and capable of operating at 1,200°C with off-gas residence times of two seconds. Supply air will be provided to ensure the oxygen levels are maintained at the optimum level (10 to 15%) to ensure the desired oxidation reactions reach completion. The fuel flow must be adjusted to maintain the reaction temperature above the minimum set point. The oxidizer will operate to obtain 99.99% destruction and removal efficiency (DRE). To ensure complete

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treatment of off-gas constituents, the thermal oxidizer will operate during both low and high temperature modes.

Quench Tower

The high temperature off-gas from the thermal oxidizer, which is essentially free of particulate, will enter the quench tower. The quench tower will be a wet quencher capable of lowering the temperature of the off-gas from the thermal oxidizer to 95°C, and it will consist of two or more water spray nozzles. Scrub solution (water) will be used as the evaporation media to lower the off-gas temperature. Spent scrub solution and condensate will drain from the bottom of the quench tower through a jack-leg and back to the scrub tank, and spray water will re-circulate from the scrub tank to the spray nozzle after cooling. Wastewater from the quench tower and scrub tank will be transferred to the wastewater stabilization system for treatment prior to disposal at the ICDF.

Venturi Scrubber

Venturi scrubber systems are commonly used in many different industries. In this application, it will be used for gas cooling, acid gas control, particulate removal, and scrubbing of certain condensable fractions contained in the off-gases. Scrub solution (water) will be sprayed into the Venturi throat to remove the fine particulates and condensable components in the off-gas. The off-gas passing through the throat will atomize the spray, resulting in a high collection efficiency for small particulates.

Stabilization/Amalgamation Station

Prior to stabilization/amalgamation, the waste from the wet spray scrubber will be containerized and sampled (10% of the containers generated per batch). Characterization will identify the individual constituents and their concentrations for use in stabilization recipe development. Once the recipe is developed, prescribed amounts of stabilization/amalgamation agent (Portland Cement, grout, Aquaset, etc.) and water will be added directly to the waste containers, where they will be mixed using an "in-drum" paddle mixer. After completion of the stabilization process, the containers will be staged pending hardening and re-characterization. Re-characterization will be performed to ensure that the final waste form meets the WAC of the pre-determined TSDF (ICDF, NTS, etc.). Once it has been determined that the waste meets the WAC, the containers will be staged pending shipment for disposal.

Mist Eliminator

The off-gas from the condenser will enter the ME vessel, which will remove the remainder of the liquid entrained in the off-gas. Entrained liquid will be removed by a stainless steel wire mesh, collected in the bottom of the ME, and drained into the low temperature surge tank. The ME will be sized for a large gas flow rate. The reduced flow through the oversized ME increases the residence time and, therefore, increases the efficiency of the unit. The residual liquid removed will be pumped to the low-temperature holding tank for treatment and disposal.

Heater

The off-gas leaving the mist eliminator will be heated to 150°C to prevent condensation in the downstream HEPA filters. An electrical heater will be used, with the temperature of the off-gas exiting

the HEPA filters to control the heater. The HEPA filter outlet temperature must be maintained above the dew point of the gas stream.

Activated Carbon/Sulfur Absorbent

The GAC beds (sulfur and non-sulfur impregnated) remove any residual organics, PCBs and elemental mercury remaining in the off-gas after scrubbing or condensing operations. After these constituents are removed, the off-gas is routed to a blower that discharges to the atmosphere.

There are two parallel trains of three GAC beds in series. The first GAC bed in each train is the primary bed, and the second and third are used as polishing beds. The primary bed is granular activated carbon for organics removal. The polishing beds are sulfur impregnated granulated activated carbon (i.e., Mersorb) for mercury removal. Mercury loading on the SGAC filters will be 10–15 wt%. A two second residence time is required. When the primary or secondary beds in a train are saturated, the train will be taken out of service and the saturated beds replaced. VOC and mercury concentrations will be monitored following each bed. In the event VOC and/or mercury are detected, valves will automatically route off-gas through the other parallel train.

The GAC beds will be shipped to an off-Site TSDF (i.e., Envirocare, Permafix, etc.) for treatment and disposal due to the VOC concentrations present after use. SGAC beds will be macroencapsulated and disposed of at the ICDF as debris.

HEPA Filter(s)

The off-gas stream flows through one bank of HEPA filters prior to entering the blower for discharge. They are placed after the GAC filters to remove aerosolized activated carbon and to prevent it from reaching the environment. The primary bank consists of three HEPA filters in series. Parallel to the primary bank is a back-up bank of three HEPA filters that can be brought on-line in the event the filter train becomes blocked. The individual HEPA filters have dioctyl phthalate test ports between them for testing the installed condition of the filters. HEPA filtration will continue during waste treatment operations. The HEPA filters are standard 24 x 24-in. filters with a nominal capacity of 1,000 cfm. The capacity of the bank is then roughly 3,000 cfm.

Blower

The off-gas blower has a capacity of 1,250 scfm. It will be manufactured of materials that are compatible with air constituents to prevent corrosion inside the blower and ductwork. The blower will be operated while waste is being treated and handled.

4.4   Alternative 1—Thermal Desorption with On/Off-Site Disposal

Alternative 1 combines on-Site disposal of TD waste with off-Site treatment and disposal of off-gas residuals. Figure 13 presents a process flow diagram of this alternative. The numbered waste streams in Figure 13 correspond with Table 8. Liquid and sludge waste will be removed from each of the V-tanks using the AEA fluidic jet removal system (or equivalent) and pumped directly to the TD unit (5-ft diameter and 16-ft long) in 100-gallon allotments. The following soil/waste mixture batch quantities will be needed: 869 gallons of soil/batch from V-1, 839 gallons of soil/batch from V-2, 834 gallons of soil/batch from V-3, and 700 gallons of soil/batch from V-9. Once the soil/waste has been received, the

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TD unit will be set in rotation and heated for one hour at 95°C at 620 mm Hg (low temperature mode of operation). During this period, 100% of the liquid and low temperature organic contaminants and 20% of the mercury will be desorbed.
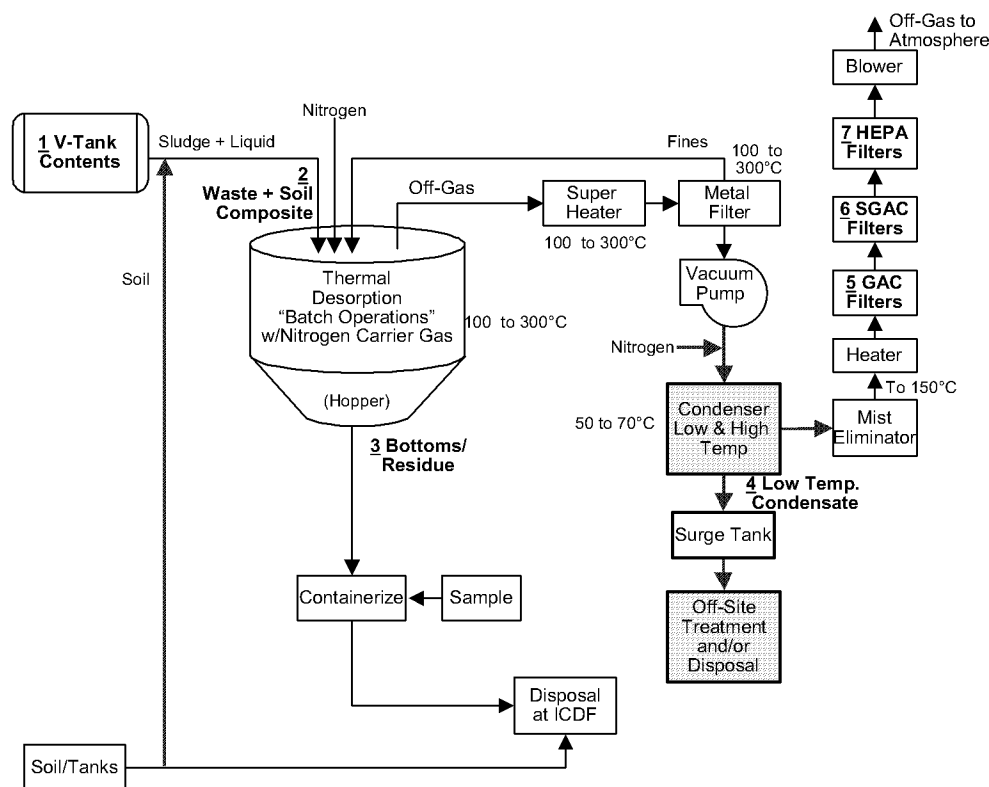

Figure 13. TD on/off-Site process flow diagram.

Following low temperature operations, a vacuum (40 mm Hg) will be established on the rotating vessel, and the unit will be heated for two hours at 300°C (high temperature mode of operation). It is during this period that 100% of the SVOCs and the remaining mercury will be desorbed. The purge rate of nitrogen gas will be 0.5 feet/sec during low temperature operations and 1 foot/sec during high temperature operations. For both low and high temperature operations, off-gas will flow to the nonMACT compliant off-gas treatment train for removal prior to release (see section 4.3.6 for equipment and process descriptions). Also, during high temperature operations, the condenser, mist eliminator, and heater will be by-passed to maintain the off-gas temperature (after nitrogen dilution) and to avoid condensation prior to the GAC/SGAC filters. After high temperature operation, the waste containing the majority of the heavy metals and radionuclides will be cooled and transferred to the hopper vessel for containerization. After packaging, all residues and liquid waste will be sampled and treated as required to meet TSDF disposal criteria. For this alternative, the TD residue will be stabilized and disposed of at the ICDF, and the off-gas residuals (condenser solutions, etc.) will be shipped off-Site for treatment and disposal.

4.4.1 Mass Balance Summary

The ability of this technology to generate waste streams that can be treated and disposed of is critical to this engineering evaluation. Mass balance calculations were completed to verify the presence and concentration for each of the CFTs. These calculations have been summarized in Table 8. Further information on these and other constituents can be found in the detailed mass balance calculations included in Appendix C.

4.4.2 Disposition Pathways

All waste generated as a function of this technology will be disposed of at an approved TSDF. Figure 14 provides a visual summary of the waste distribution for each component. Table 9 identifies the individual disposition strategies for the waste forms at the TSDFs.

4.5 Alternative 2—Thermal Desorption with On-Site Disposal

Alternative 2 combines on-Site disposal of TD waste with on-Site treatment and disposal of off-gas residuals. Figure 15 presents a process flow diagram of this alternative. The numbered waste streams correspond with Table 10. Liquid and sludge waste will be removed from each of the V-tanks using the AEA fluidic jet removal system (or equivalent) and pumped directly to the TD unit (5-ft. diameter and 16-ft. long) in 100-gallon allotments. The following soil/waste mixture batch quantities will be needed: 869 gallons of soil/batch from V-1, 839 gallons of soil/batch from V-2, 834 gallons of soil/batch from V-3, and 700 gallons of soil/batch from V-9. Once the soil/waste has been received, the TD unit will be set in rotation and heated to 95°C for one hour at 620 mm Hg (low temperature mode of operation). During this period 100% of the liquid and low temperature organic contaminants and 20% of the mercury will be desorbed.

Following low temperature operations, a vacuum (40 mm Hg) will be established on the rotating vessel, and the unit will be heated for two hours at temperatures up to 400°C (high temperature mode of operation). It is during this period that 100% of the SVOCs and the remaining mercury will be desorbed. The purge rate of nitrogen gas will be 0.5 ft/sec during low temperature operations and 1 ft/sec during high temperature operations. After high temperature operation, the waste containing the majority of heavy metals and radionuclides will be cooled and transferred to the hopper vessel for containerization, sampling, treatment, and on-Site disposal.

For this alternative, the organic species in the off-gas will be destroyed (thermally oxidized), thus resulting in compliance with MACT requirements. The process residuals will be disposed of at the ICDF (see Section 4.3.7 for equipment and process descriptions). For on-Site off-gas treatment, the condenser has been replaced with a flameless thermal oxidizer, a quench tower, and a wet spray scrubber. The thermal oxidizer will treat organics (TCE, PCE, PCBs, etc.) via oxidation at 1,000 to 1,200°C. To do so, oxygen levels, temperature, and residence time will be controlled to ensure complete contaminant destruction. The quench tower will lower the off-gas temperature sufficiently for direct feed to the wet spray scrubber, where 60% of the mercury and 99% of the residual liquid will be removed. The remaining mercury will be captured downstream on the SGAC filters. The primary waste streams after thermal oxidation are quench water, demister water, and scrubber solution contaminated with mercury and trace radionuclides (i.e., Cs-137). This waste will be treated (neutralized, stabilized, amalgamated, etc.) to meet LDRs and disposed of at the ICDF.

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Table 8. Summary mass balance for the TD - on/off-Site process.

Stream Name	V-tank Contents	Waste+Soil Composite	Bottoms Residue	Low Temp. Condensate	GAC Filters	SGAC Filters	HEPA Filters
Stream Number	1	2	3	4	5	6	7
Volume (L)	2.24E+04	1.82E+05		5.03E+04	1.84E+4	9.91E+01	
Mass (kg)	2.26E+04	3.04E+05	2.43E+05	5.03E+04	7.36E+3	3.96E+01	
Component							
Inorganics							
Cd (mg/kg)	2.02E+01	1.49E+00	1.86E+00				
Chlorides (ppm)	1.36E+02	1.67E+01	2.06E-03		1.65E+2		
Cr (mg/kg)	5.96E+02	4.44E+01	5.54E+01				
Hg (mg/kg)	2.59E+02	1.93E+01	2.35E-02	1.50E+01		1.29E+4	
Pb (mg/kg)	2.82E+02	2.00E+01	2.62E+01				
VOC							
PCE (ppm)	2.37E+02	2.91E+01	0.00E+00	2.14E+01	2.30E+2		
TCA (ppm)	1.05E+02	1.29E+01	0.00E+00	9.42E+00	1.02E+2		
TCE (ppm)	8.54E+02	1.05E+02	0.00E+00	7.71E+01	8.28E+2		
SVOC							
BEHP (ppm)	9.10E+02	1.12E+02	8.81E-02		1.11E+3		
PCBs (ppm)	3.59E+01	4.42E+00	3.44E-03		4.36E+1		
Radionuclide							
Cs-137 (nCi/g)	1.98E+03	1.47E+02	1.84E+02	trace	trace		trace
Sr-90 (nCi/g)	3.68E+03	2.74E+02	3.41E+02	trace	trace		trace
TRU (nCi/g)	8.57E+00	6.37E-01	7.97E-01	trace	trace		trace
Other							
Total Organic Carbon (ppm)	2.53E+04	3.11E+03	0.00E+00		3.08E+4		

Alternative 1
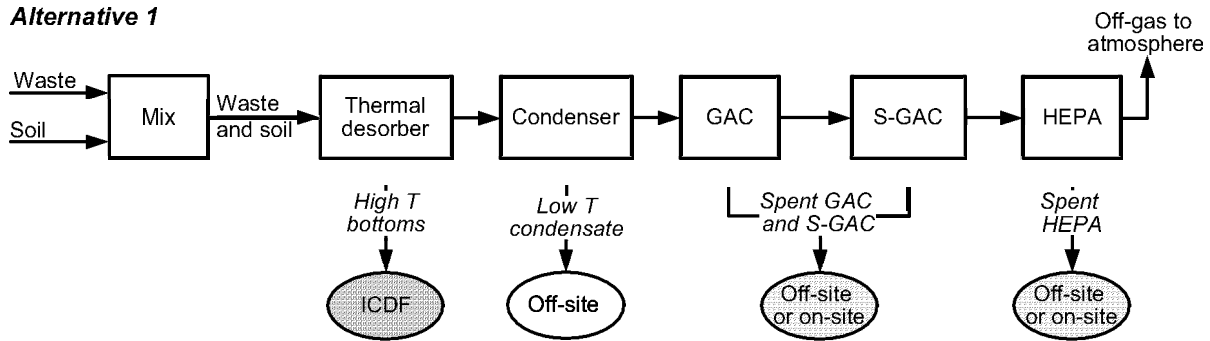
Figure 14. Summary of TD Alternative 1 waste distribution.

Table 9. Summary of waste types, volumes, expected treatments, and expected disposition for TD—on/off-Site process.

| Generated Waste Type	Volume	Expected Treatment	Expected Disposition
PRIMARY WASTE	**2407 m³**		
Bottoms/Residue (Item 3 in PFD)	203 m³	None – Calculations predict stabilization not required	ICDF
Contaminated Soil/tanks from V-tank AOC	2204 m³	Excavated (no treatment)	ICDF
SECONDARY WASTE	**133 m³**		
Low temperature condensate (Item 4 in PFD)	48.3 m³.	Combustion and Stabilization for disposal	Permafix Treatment Envirocare (Disposal)
GAC Filters (Item 5 in PFD)	24.9 m³	Macroencapsulation for **Disposal**	Envirocare
SGAC Filters(Item 6 in PFD)	1.1 m³	**Macroen**capsulation for Disposal	Envirocare
HEPA Filters (Item 7 in PFD)	0.7 m³	Macroencapsulation for Disposal	Envirocare
Used PPE, consumable materials, non-recoverable equipment	58.1 m³	Macroencapsulation for disposal (as needed)	ICDF (or Envirocare)
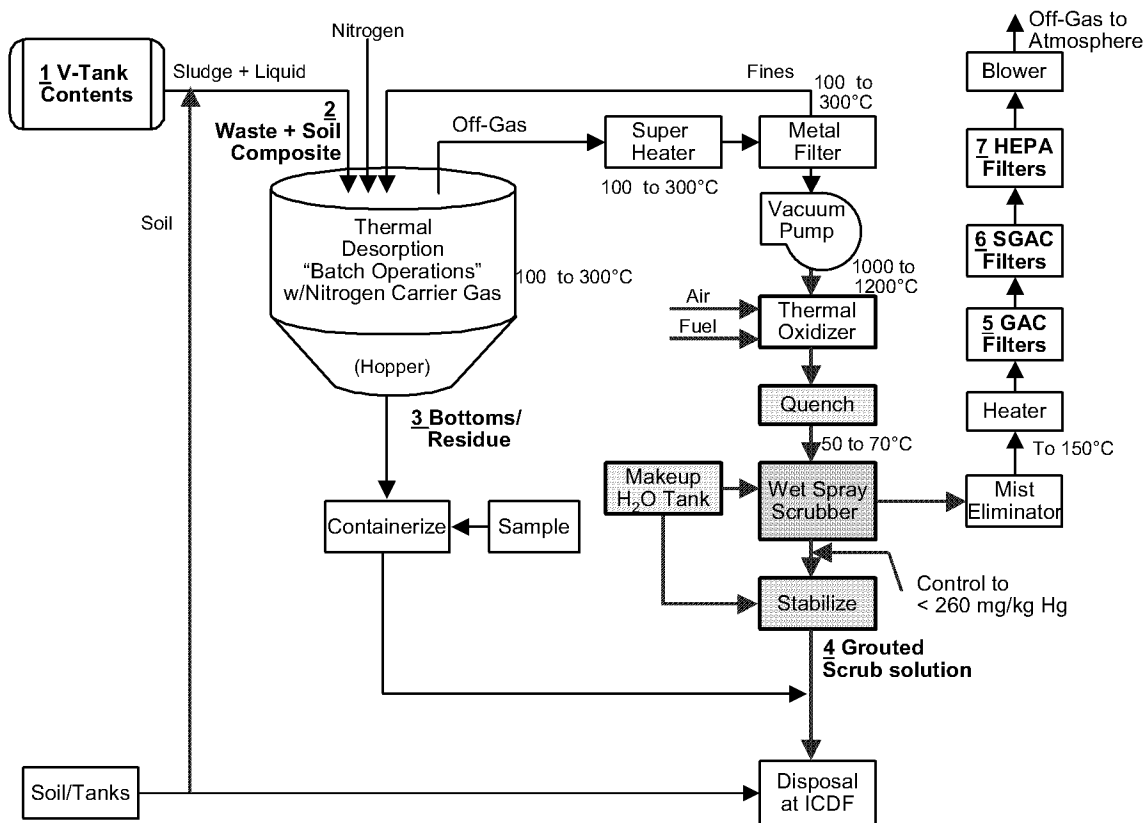
Figure 15. TD on-Site process flow diagram.

To support completion of mass balance calculations for this alternative, the following operating conditions were determined:

- Low Temperature Operation (up to 1,200°C)—The thermal oxidizer requires 3,773 kg/hr of supply air and 159 kg/hr of extra propane for treatment of all tank waste.

- High Temperature Operation (up to 1,200°C)—The thermal oxidizer requires 145 kg/hr of air for treatment of all tank waste and 1.4 kg/hr of extra fuel for treatment of Tank V-9. Extra fuel is not required for thermal oxidation treatment of waste from Tanks V-1, V-2, and V-3.

4.5.1 Mass Balance Summary

The ability of this technology to generate waste streams that can be treated and disposed of is critical to this engineering evaluation. To verify the presence and concentration for each of the CFTs, mass balance calculations were completed. These calculations have been summarized and the corresponding information included in Table 10. The minimal metal and cyanide concentrations are not significant enough to be included in the summary tables. Further information on these and other constituents can be found in the detailed mass balance calculations included in Appendix C.

Table 10. Summary mass balance for the TD on-Site process.

Stream Name	V-tank Contents	Waste+Soil Composite	Bottoms/ Residue	Grouted Scrub Solutions	GAC Filters	SGAC Filters	HEPA Filters
Stream Number	1	2	3	4	5	6	7
Volume (L)	2.24E+04	1.82E+05	2.43E+05	1.41E+4	2.49E+4	5.89E+3	
Mass (kg)	2.26E+04	3.04E+05	2.43E+05	1.41E+4	9.97E+3	2.36E+3	
Component							
Inorganics							
Cd (mg/kg)	2.02E+01	1.49E+00	1.86E+00				
Chlorides (ppmv)	1.36E+02	1.67E+01	2.06E-03	2.16E+2			
Cr (mg/kg)	5.96E+02	4.44E+01	5.54E+01				
Hg (mg/kg)	2.59E+02	1.93E+01	2.35E-02	1.50E+2	1.11E+2	1.11E+3	
Pb (mg/kg)	2.82E+02	2.00E+01	2.62E+01				
VOC							
PCE (ppmv)	2.37E+02	2.91E+01	0.00E+00				
TCA (ppmv)	1.05E+02	1.29E+01	0.00E+00				
TCE (ppmv)	8.54E+02	1.05E+02	0.00E+00				
SVOC							
BEHP (ppmv)	9.10E+02	1.12E+02	8.81E-02				
PCBs (ppmv)	3.59E+01	4.42E+00	3.44E-03				
SVOCs (ppmv)	2.78E+01	3.42E+00	0.00E+00				
Radionuclide							
Cs-137 (nCi/g)	1.98E+03	1.49E+02	1.84E+02		trace	trace	trace
Sr-90 (nCi/g)	3.68E+03	2.74E+02	3.41E+02		trace	trace	trace
TRU (nCi/g)	8.57E+00	6.37E-01	7.97E-01		trace	trace	trace
Other							
Total Organic Carbon (ppmv)	2.53E+04	3.11E+03	0.00E+00				

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4.5.2   Disposition Pathways

All waste generated as a function of this technology will be disposed of at an approved TSDF.
Figure 16 provides a visual summary of the waste distribution for each component. It is assumed that the
liquid from the quench, scrubber, and demister will be combined prior to treatment and disposal. Table 11
identifies the individual disposition strategies for the waste forms at the TSDFs.
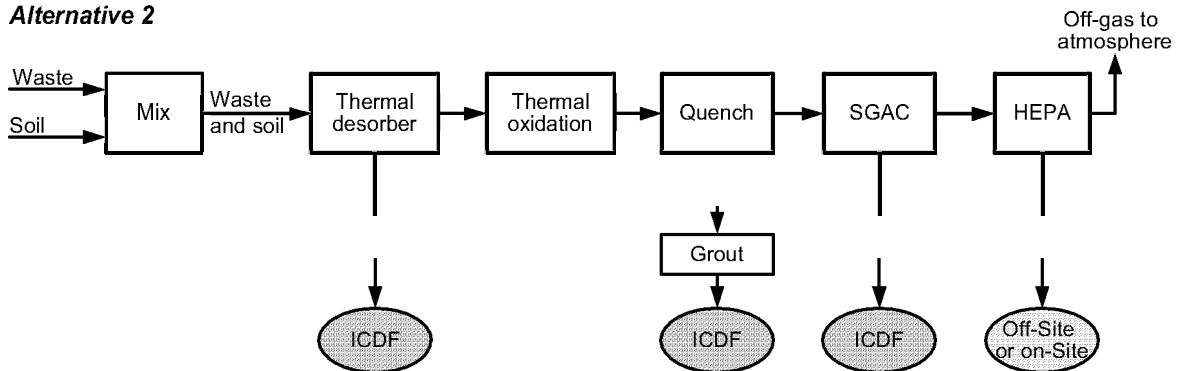

Table 11. Summary of waste types, volumes, expected treatments, and expected disposition for the TD
on-Site process.

Generated Waste Type	Volume	Expected Treatment	Expected Disposition
PRIMARY WASTE	**2407 m³**		
Bottoms/Residue (Item 3 in PFD)	203 m³	None – Calculations indicate Stabilization not required	ICDF
Contaminated Soil/tanks from V-tank AOC	2204 m³	Excavated (no treatment)	ICDF
SECONDARY WASTE	**110 m³**		
Grouted Scrub Solution (Item 4 in PFD)	16.5 m³	Stabilize & Disposal	ICDF
GAC Filters (Item 5 in PFD)	5.7 m³	Macroencapsulation for Disposal	ICDF
SGAC Filters (Item 6 in PFD)	5.7 m³	Macroencapsulation for Disposal	ICDF
HEPA Filters (Item 7 in PFD)	0.7 m³	Macroencapsulation for Disposal	ICDF
Used PPE, consumable materials, non-recoverable equipment	81.7 m³	Macroencapsulation for disposal (as needed)	ICDF (or Envirocare)

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4.6   Alternative 3—Off-Site Thermal Desorption

Alternative 3 provides for off-Site treatment and disposal of TD waste and off-gas residuals (NTS, Hanford, etc.). Figure 17 presents a process flow diagram of this alternative. The numbered waste streams correspond with Table 12. Liquid and sludge waste will be removed from each of the V-tanks using the AEA fluidic jet removal system (or equivalent) and pumped directly to the TD unit (4-ft diameter and 8.5-ft long) in 200-gallon batches. The first two TD alternatives require adding soil to the waste to maintain the feed soil moisture content within the demonstrated technology operating limits. The third TD alternative uses a smaller unit, as soil is not added. No soil addition may push the technology operating limits, but may also make it possible to dispose of the waste at WIPP. Once the waste has been received, the TD unit will be set in rotation and heated for two hours at 95°C at 620 mm Hg (low temperature mode of operation). During this period, 100% of the liquid and low temperature organic contaminants and 20% of the mercury will be desorbed.

Following low temperature operations, a vacuum (40 mm Hg) will be established on the rotating vessel, and the unit will be heated for one hour at temperatures up to 400°C (high temperature mode of operation). It is during this period that 100% of the SVOCs and the remaining mercury will be desorbed. The purge rate of nitrogen gas will be 0.5 ft/sec during low temperature operations and 1 ft/sec during high temperature operations. For both low and high temperature operations, off-gas will flow to the non-MACT compliant off-gas treatment train for treatment prior to release (see Section 4.3.6 for equipment and process descriptions). Also, during high temperature operations, the condenser, mist eliminator, and heater will be by-passed to maintain the off-gas temperature (after nitrogen dilution) and to avoid condensation prior to the GAC/SGAC filters. After the high temperature operation, the inorganic waste containing the majority of the heavy metals and radionuclides will be cooled and transferred to the hopper vessel for containerization.

As with all TD alternatives, significant radiation shielding and semi-remote operating methods will be required for the materials transfer subsystems. However, dose rates will be significantly higher with this alternative without the soil added to the TD unit for TD Alternatives 1 and 2. The soil addition had the side benefits of diluting the radionuclides and providing some self shielding. Radiological contamination control for the transfer of bottoms from the TD unit to a receiving vessel and from the receiving vessel into containers (including sampling, stabilization, handling, storage, and transportation activities), will be significantly more difficult than for the first two TD alternatives due to the much greater radionuclide concentrations. This will be a very difficult engineering, safety basis, and procedural challenge due to the dry, very fine material and the fact that this is to be a one-time short-duration operation. The shielding, contamination control, and remote operating methods needed for this alternative could prove to be prohibitively costly.

After containerization, the waste will be placed in interim storage and shipped to an off-Site disposal facility such as WIPP, NTS, or Hanford. In the event TRU levels (as measured using real time radiological analysis) meet WIPP criteria, the residue will be stored without stabilization. If the TRU levels don't meet WIPP criteria, the residue will be stabilized to meet LDRs and comply with NTS and Hanford waste acceptance criteria and radiological licenses. These sites are currently accepting only mixed waste from within their respective states and are pursuing the capability to receive out-of-state wastes. Since they are not currently authorized to accept the V-tanks' waste, it is assumed that the waste (inorganic residue) will be placed in on-Site interim storage until authorization is granted.
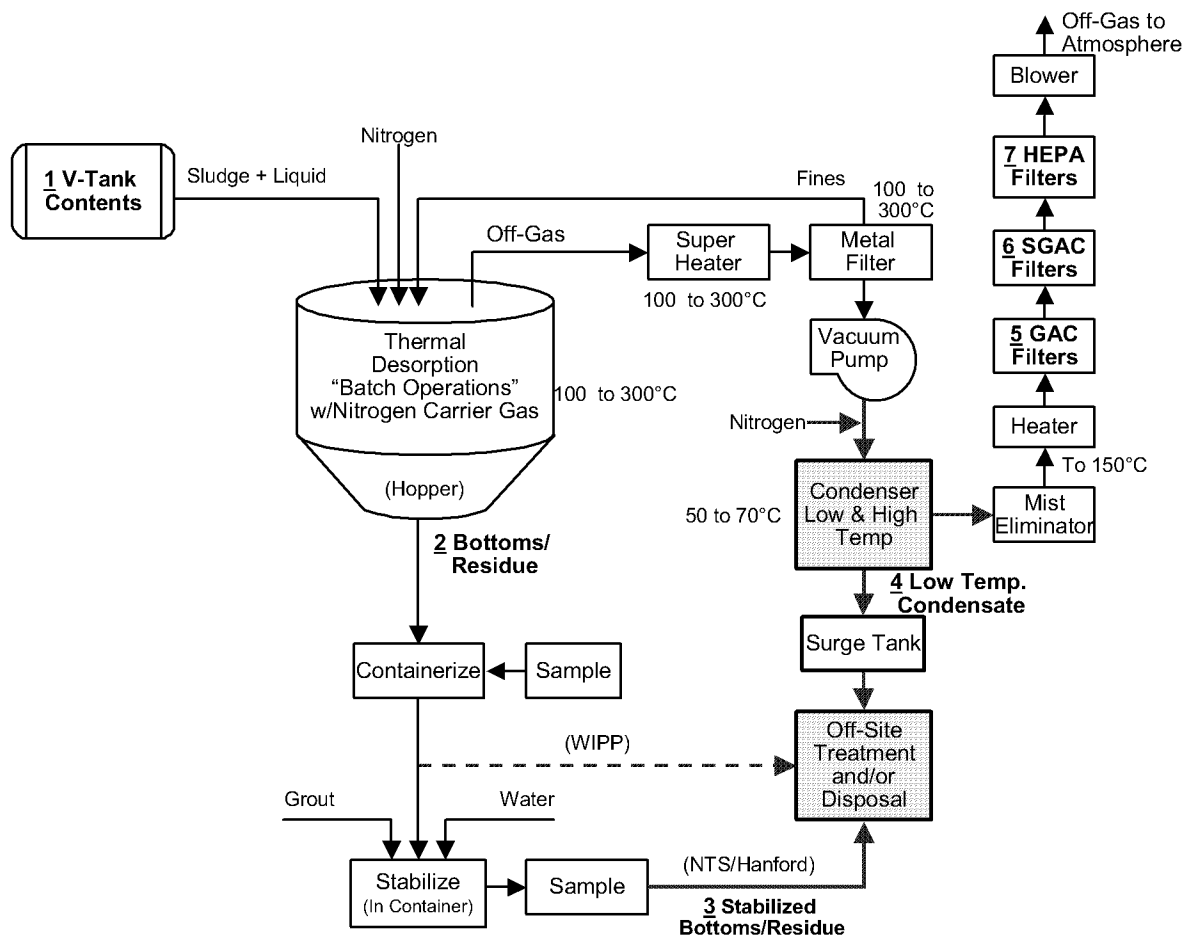
Figure 17. TD off-Site process flow diagram.

Table 12. Summary mass balance for the TD - off-Site process.

Stream Name	V-tank Contents	Bottoms/ Residue	Stabilized Bottoms/ Residue	Low Temp. Condensate	GAC Filters	SGAC Filters	HEPA Filters
Stream Number	1	2	3	4	5	6	7
Volume (L)	2.24E+04	2.80E+03	5.0E+03	1.37E+04	1.84E+4	6.51E+02	
Mass (kg)	2.26E+04	2.80E+03	7.0E+03	1.37E+04	7.36E+3	2.60E+02	
Component							
Inorganics							
Cd (mg/kg)	2.02E+01	1.61E+02	6.46E+01				
Chlorides (ppmv)	1.36E+02	1.84E-01	1.05E-01		1.65E+2		
Cr (mg/kg)	5.96E+02	4.81E+03	1.92E+3				
Hg (mg/kg)	2.59E+02	1.68E+00	1.11E+00	5.14E+01		1.97E+4	
Pb (mg/kg)	2.82E+02	2.28E-03	9.10E+02				
VOC							
PCE (ppmv)	2.37E+02	0.00E+00	0.00E+00	7.94E+01	2.29E+2		
TCA (ppmv)	1.05E+02	0.00E+00	0.00E+00	3.47E+01	1.02E+2		
TCE (ppmv)	8.54E+02	0.00E+00	0.00E+00	2.84E+02	8.28E+2		
SVOC							
BEHP (ppmv)	9.10E+02	7.63E+00	4.4E+00		1.11E+3		
PCBs (ppmv)	3.59E+01	3.07E-01	1.75E-01		6.36E+1		
Radionuclide							
Cs-137 (nCi/g)	1.98E+03	1.60E+6	6.39E+3	trace	trace	trace	trace
Sr-90 (nCi/g)	3.68E+03	2.98E-04	1.19E+04	trace	trace	trace	trace
TRU (nCi/g)	8.57E+00	6.92E+01	2.77E+01	trace	trace	trace	trace
Other							
Total Organic Carbon (ppmv)	2.53E+04	0.00E+00	0.00E+00		3.08E+4		

4.6.1 Mass Balance Summary

The ability of this technology to generate waste streams that can be treated and disposed of is critical to this engineering evaluation. To verify the presence and concentration for each of the CFTs, mass balance calculations were completed. These calculations have been summarized and the corresponding information included in Table 12. The minimal metal and cyanide concentrations are not significant enough to be included in the summary tables. Further information on these and other constituents can be found in the detailed mass balance calculations included in Appendix C.

4.6.2 Disposition Pathways

All waste generated as a function of this technology will be disposed of at an approved TSDF. The waste distribution for each component is shown in Figure 18. Table 13 identifies both the waste and the TSDF where said waste will be treated and/or disposed of.
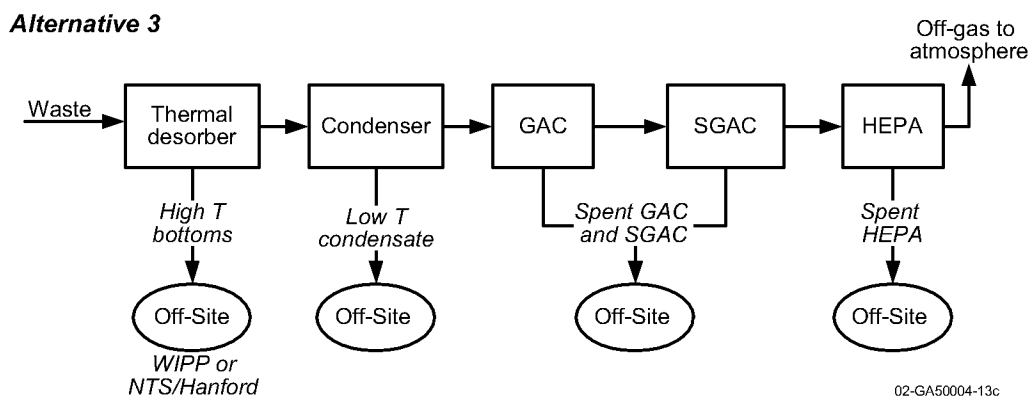

Figure 18. Summary of TD Alternative 3 waste distribution.

Table 13. Summary of waste types, volumes, expected treatments, and expected disposition for the TD off-Site process.

Generated Waste Type	Volume	Expected Treatment	Expected Disposition
PRIMARY WASTE	**2397 m³**		
Stabilized Bottoms/Residue (Item 3 in PFD)	2.4 m³ unstabilized, 5 m³ stabilized	None	NTS, Hanford
Contaminated Soil/tanks (from V-tank AOC)	2392 m³	Excavated (no treatment)	ICDF
SECONDARY WASTE	**93 m³**		
Low Temperature Condensate (Item 4 in PFD)	13.1 m³	Combustion and Stabilization for disposal	Perma-fix Treatment Envirocare (Disposal)
GAC Filters (Item 5 in PFD)	24.9 m³	Macroencapsulation for Disposal	Envirocare
SGAC Filters (Item 6 in PFD)	1.1 m³	Macroencapsulation for Disposal	Envirocare
HEPA Filters (Item 7 in PFD)	0.7 m³	Macroencapsulation for Disposal	Envirocare
Used PPE, consumable materials, non-recoverable equipment	53.4 m³	Macroencapsulation for disposal (as needed)	ICDF (or Envirocare)